CHRONOPSYCHOLOGICAL LEARNING EFFECTS OF RAPIDLY-ROTATING SHIFT WORK ON DAY-SHIFT ATTENTION

By

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The purpose of this study was to determine if an objectively-measurable day-shift attention decrement or learning deficiency exists among rapidly-rotating shift workers. Research using subjective rating scales indicates that this type of shift work is associated with a lack of alertness during day-shift hours. An attention decrement may cause learning deficiencies during day-shift training sessions, or problems with dynamic situation awareness on the job.

For this study, 37 air traffic controllers (aged under 46 years) were recruited from the Jacksonville Air Route Traffic Control Center as volunteer participants. Group 1 consisted of 18 rapidly-rotating

three-shift workers (15 male/3 female), and Group 2 consisted of 19 day/evening two-shift workers (16 male/3 female).

Each participant completed 25 sessions on the NovaScan computer-based performance test to determine two baseline measures of attention allocation (one during a spatial-visualization task and the other during a tracking task). The mean baseline measures for the groups were compared using t-tests. The mean learning curves for the groups were compared on five variables (attention allocation during the spatial-visualization task, attention allocation during the tracking task, response flexibility in switching resources, non-transition reaction to spatial visualization, and tracking error during tracking). The learning curves' slopes and residuals were compared using a two-way general linear model, repeated-measures analysis, which included three statistical tests (group main effect, time main effect, and group-time interaction).

The t-tests determined that the rapidly-rotating shift workers have a significantly better attention allocation ability than the day/evening shift workers on both variables measured. The learning curve comparisons indicated that the rapidly-rotating shift workers improved their attention allocation ability during the spatial visualization task, while the day/evening shift workers did not, and that the two groups stabilized around their means at different rates on the learning curve for attention allocation during the tracking

task. No differences were found between the groups' learning curves for the three other variables. It is suggested that day and evening shift workers may practice irregular sleep-wake schedules and/or accumulate a greater sleep debt during the work week than do rapidly-rotating shift workers.

CHAPTER 1
INTRODUCTION

The occupation of air traffic controller carries with it a great responsibility in terms of both life and property, in that the controller's job requires him/her to maintain the safe and expeditious flow of air traffic in his/her area of responsibility. McAdaragh (1995) has demonstrated that many controllers work rotating work schedules that have been shown to induce circadian dysrhythmia, a misalignment or desynchronization of an individual's biological and/or psychological daily rhythmic cycles (Hawkins, 1987). Chronopsychological research (the study of behavioral and psychological rhythms) indicates that these type of work schedules produce a high degree of subjective fatigue in these individuals during midnight and day shifts, with the lowest degree being reported on the evening shifts (Melton, 1985; Monk et al., 1988; Saldivar et al., 1977; Smith et al., 1971). The term "shift-work insomnia" has been used to describe the condition caused by circadian dysrhythmia which reduces the total amount of sleep achieved by affected individuals who work shift work (Akerstedt & Kecklund, 1991).

Babkoff et al. (1991) determined that subjective sleepiness ratings of individuals during periods of sleep deprivation are dependent upon the phase of each individual's circadian cycle. Manber et al. (1996) demonstrated that, even when a normal full-night's sleep is achieved by both groups, individuals who sleep at irregular schedules report a lesser amount of alertness and a greater amount of sleepiness during the day than do individuals who sleep at regular sleep-wake schedules. Billiard et al. (1987), in a study involving French military draftees, found that sleep difficulties and irregular sleep-wake schedules were major factors contributing to excessive daytime somnolence in young men between the ages of 17 and 22 years of age.

Circadian dysrhythmia has also been shown to cause performance decrements in affected individuals (Higgins, et al., 1975; Monk et al., 1988), and dysrhythmia and sleep deprivation have been shown to produce a learning effect (Rankin et al., 1989). Luna et al. (1997), in a study of air traffic controllers working a rapidly rotating schedule, found that controllers on the midnight shift of a forward rapidly-rotating schedule appeared to be falling asleep and reported increased confusion and fatigue. In a telephone conversation concerning this study on March 31, 1997, Dr. French advised the author that, although the performance data collected was

not reported due to a lack of sufficient data, the data that were collected indicated a significant negative initial learning effect for the controllers while they were on the midnight shift relative to when they were on the day or evening shifts. Pilcher and Huffcut (1996) found, through a meta-analysis of sleep-deprivation studies, that sleep deprivation has its greatest effect on mood with a lesser effect on cognitive performance and motor performance in descending order. They also determined that partial sleep deprivation (sleep loss which occurs whenever there is a reduction in the usual amounts of sleep obtained in a 24-hour period), rather than long-term or short-term sleep deprivation, has a greater negative effect on mood and cognitive performance. This is important to shift workers, because partial sleep deprivation results from the condition known as "shift-work insomnia" which, in turn, results from working irregular or rotating schedules.

Pilcher and Huffcut also indicate that one clear goal of future research will be to determine why partial sleep deprivation has such a pronounced effect on mood and cognitive performance.

> For example, partial sleep deprivation may alter certain circadian rhythm effects on performance and mood. While total sleep deprivation has been found to interact with circadian rhythms (Monk et al., 1985; Naitoh et al., 1985), few studies have investigated the effects of partial sleep deprivation on circadian rhythms. In addition, partial sleep deprivation may be similar to fragmented sleep in that subjects in both cases obtain

> at least some sleep. Since sleep fragmentation has been shown to significantly decrease performance and mood (Bonnet, 1986; Bonnet, 1989), it is possible that the effects of partial sleep deprivation more closely resemble those of sleep fragmentation than those of total sleep deprivation. Furthermore, partial sleep deprivation could have a unique effect on certain psychological variables. Decreased interest and attention, for example, are thought to be two prominent variables related to total sleep deprivation (Meddis, 1982) and could be investigated with partial sleep deprivation.... In sum, the effects of partial sleep deprivation need to be more thoroughly investigated, particularly since partial sleep loss is a relatively common condition in our society. (p.324)

Statement of the Problem

The Federal Aviation Administration (FAA) defines an Operational Error as: "An occurrence attributable to an element of the air traffic system which: (1) Results in less than the applicable separation minimum between two or more aircraft, or between an aircraft and terrain or obstacles as required by FAA 7110.65, Air Traffic Control, and supplemental Instructions. Obstacles include vehicles, equipment, and personnel on runways; or (2) Aircraft lands or departs on a runway closed to aircraft operations after receiving air traffic authorization" (U.S. Department of Transportation, Federal Aviation Administration, Air Traffic Rules and Procedures Service, 1996, p. 5-1-1). Each year there are a number of operational errors in the air traffic system, many of which are attributed to controller error. In 1996, there were 792 operational errors

nation-wide, or about 0.53 operational errors per 100,000 facility activities in the air traffic system (U.S. Department of Transportation, Federal Aviation Administration, 1997, p. 6).

Some operational errors result in aircraft accidents. In 1996, there were 38 large air carrier, 12 commuter, 88 air taxi, 1,911 general aviation, and 182 rotor craft accidents (U.S. Department of Transportation, Federal Aviation Administration, 1997, p. 4). Some of these accidents were the result of controller error. Based on what is known about chronopsychology and circadian dysrhythmia, it is very possible that at least some of the so-called controller errors are the result of a failure on the part of controllers to follow procedures, either because of degraded performance while working, or because of a failure to fully acquire information concerning these procedures during training. These controllers may not be assimilating some information during training sessions due to a degraded attention allocation and a negative learning effect which are brought on by the dysrhythmic condition.

Need for the Study

Air traffic controllers need to be in a high state of alertness while performing their duties, and while undergoing training on new procedures or during refresher training of prior learning. Redding's (1992) analysis of operational errors and workload in air traffic

controllers has demonstrated that a loss of situation awareness is the primary cause of controller error, and Endsley (1995) has described a model of situation awareness which includes training as a contributing factor to situation awareness in dynamic situations.

Controllers currently work a variety of shift-work schedules, but in many facilities they are most likely to receive training during administrative hours, while they are working day shifts. These training sessions usually take the form of a group presentation in a classroom setting and do not address the individual differences among the learners' chronopsychological rhythms. Based on the aforementioned research, controllers who work dysrhythmia-inducing work schedules should be experiencing, to at least some degree, decrements in performance, somnolence, and most probably a negative chronopsychological learning effect (a negative learning effect due to a decreased interest or ability to concentrate and focus their attention) while attending these training sessions. These decrements can be expected to be present in these controllers due to irregular sleep/wakefulness cycles, sleep loss (due to shift work insomnia), and fatigue, which are all induced by rotating or irregular work schedules.

Training involves instruction, and instruction is designed with the goal of accomplishing the objectives of the training. Learning

theory and research in the cognitive and behavioral sciences provide many principles which are used in the design of instruction, and instructional design addresses many variables in order to accomplish these instructional objectives. The design process takes into account learning modalities, styles, and strategies, while giving a great amount of attention to individual learner characteristics, instructional settings, instructional media selection and learning activity development. These variables are all considered during the design process in order to maximize learning for the target audience.

Research in chronopsychology addresses such variables as short-term and long-term memory, attention and alertness, subjective fatigue and mood, and cognitive performance issues such as the ability to synthesize information, all of which express rhythmic cycles in humans. Even in instructional settings where learners have regular diurnal circadian rhythms, these variables have great implications for the design of instruction. But when it is taken into consideration that many industrial, military, and government workers work shift work and are susceptible to its consequences, it becomes apparent that research in chronopsychology offers a wealth of information and research opportunity to the field of instructional design. Even though this is the case, at present there is very little, if

any, mention of chronopsychology or its principles in the literature of instructional design.

Shift work and instructional design are usually found sharing a common niche in society. Instructional design is most widely used in industry and the miiitary, where it has its foundations. These are also areas where a large number of personnel work rotating shift work and night work. In fact, statistics suggest that approximately 20 percent of the American work force is now engaged in shift work (Venar et al., 1989).

Shift work and night work have been shown to have a negative effect on individuals' circadian rhythms (the daily physiological and psychological rhythms of the body and mind) in much the same manner as transmeridian flight produces the negative state known as "jet lag." The condition which results in an individual in either situation is known as circadian dysrhythmia, a desynchronization of the body's daily rhythmic cycles.

Research indicates that jet lag or shift work affects many individuals with decrements to health (Vener et al., 1989), and, as mentioned earlier, subjective sleepiness and fatigue during day and night shifts, as well as overall decrements in performance. It has also been demonstrated that irregular sleep-wake schedules are a cause of alertness disorders (Billiard et al., 1987), and that the timing

of sleep termination may be closely related to the sleepiness/alertness rhythm (Akerstedt & Gillberg, 1980). This line of research implies that shift workers, such as air traffic controllers, may suffer from an alertness disorder that could cause an attention decrement. If such a decrement were to be identified in controllers who are engaged in rotating shift work during day shift hours (when training sessions are scheduled at many facilities), it could imply a need to amend future instructional strategies to address this variable when considering instructional activities and media selection.

Research concerning diurnal psychological rhythms also demonstrates implications for instructional design for normal day-shift workers. According to Folkard and Monk (1980), short-term and long-term memory rhythms demonstrate implications for the timing of instruction depending on the type of instructional objective. Englund (1979) has demonstrated a diurnal function of reading rate, comprehension, and efficiency which implies a relationship with memory, body temperature, and general activity cycles of circadian rhythms. Reading rate and comprehension peak at different times of the day, while reading efficiency is maintained.

According to Adan (1993), analysis of the psychological or behavioral variables of circadian rhythms (chronopsychology) is recent and still developing. She indicates that most psychological

research ignores the time-of-day factor as both a procedural variable and as a means of control in experiments. This oversight can cause erroneous results in that behaviorai parameters are not triviai and can be equivalent in magnitude to the effects experienced from limiting sleep to three hours or from ingesting the legal driving limit of aicohol.

The fact that chronopsychological parameters are significant in diurnal circadian conditions is ground enough to consider addressing these psychological rhythms when designing instruction. By so doing, designers may take advantage of learners' abilities to accomplish different objectives at different times of the day. Furthermore, the complex relationship of these same psychological variables and their resulting learner characteristics, when influenced by a variety of work schedule rotations, can and should be the focus of further research. Only then can the typical psychological principles concerning the chronopsychological effects of each type of schedule become understood. Only then can instruction be designed to take advantage of these same variables for shift workers.

Null Hypotheses

1. Air traffic controllers who work rapidly-rotating work schedules, wiii show no significant difference from controllers who work day-shift and/or evening-shift schedules on their NovaScan mean

baseline rating of attention allocation for dial monitoring during the spatial visualization task (Task #1).

2. Air traffic controllers who work rapidly-rotating work schedules will show no significant difference from controllers who work day-shift and/or evening-shift schedules on their NovaScan mean baseline rating of attention allocation for dial monitoring during the tracking task (Task #2).

3. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantiy different from the mean learning curve of controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of reaction time on dial monitoring during the spatial visualization task (Task #1).

4. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of reaction time on dial monitoring during the tracking task (Task #2).

5. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of

controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of reaction time for the transition from Task #2 to Task #1 (which indicates response flexibility in switching resources).

6. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of reaction time on Task #1 non-transition object orientation (which indicates spatial visualization).

7. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of tracking error on Task #2 (which indicates mind/motor coordination).

Limitations

Work schedule, the predictor variable, was the only variable used to differentiate the two groups of participants. Because of this, work schedule was considered as the suspected cause for any detriments that were found in this study. Circadian rhythmicity can

only be considered as a probable cause because no other social or psychological differences among the participants were controlled.

The first group of participants only included controllers who work rapidly-rotating schedules which are usually composed of day shifts, evening shifts, and night shifts. To be included in this study, schedules for participants in this group included at least one midnight shift and one day shift each week so that behavioral and psychological circadian rhythms could be expected to be dysrhythmic in the individuals working them. According to the literature, this group should be characterized by diurnal biological rhythms and desynchronous behavioral and psychological rhythms. Therefore, only desynchronous behavioral and psychological circadian rhythms were suspected as a probable cause for any decrement to day-shift attention that was determined. No determinations were made concerning biological circadian rhythms.

The second group only included controllers who work day-shift and evening-shift rotating work schedules. According to the literature, this group is expected to be characterized by diurnal circadian rhythms, with rotating work and leisure time.

Delimitations

The instrument used in this study measured variables which were used to determine attention allocation baseline ratings and

learning curves for the participants. The NovaScan instrument was designed and validated to measure an individual's performance against his/her own baseline of attention allocation, once it has been established, in order to determine readiness for duty. It has also been validated for establishing these ratings of attention allocation, and for estabiishing both individual and group learning curves for the variabies which it measures (O'Donnell, 1992, p. 19). This was the first time that this instrument was used to compare the attention ailocation baselines of two groups of individuals who are expected to differ on this variable according to literature. Evaluation of these ratings determine if one group displayed a higher mean attention allocation baseline rating, as determined by NovaScan, than the other group.

Because NovaScan has been validated for measuring attention allocation, it has logical (or face) validity for use in this study. It also has construct validity because it has been validated through research for its extreme sensitivity to decrements caused by drugs or alcohol (O'Donnell, 1992, p. 26).

The iearning curve data were used to make determinations concerning any possible learning effects between the groups compared in this study. The criterian variables measured by NovaScan in this study determined each participant's learning curve

and baseline rating for the following: (a) Two measures of attention allocation (Variables 1 and 2), (b) response flexibility in switching resources during multiple tasks performance (Variable 3), (c) spatial visualization ability (Variable 4), and (d) straight mind/motor coordination (Variable 5).

All of these variables have been shown by prior research to be negatively affected by acute shifts in routine. For example, Monk et al. (1988), demonstrated that a phase advancement of six hours in the wake period (induced jet lag in the laboratory) with middle-age male subjects resulted in several negative effects. These negative effects included the following: (a) Decreased subjectively-rated alertness (which corresponds to NovaScan Variables #1 and #2), (b) decreased performance at search tasks (which corresponds to NovaScan Variable #3), and (c) decreased performance at manual dexterity tasks (which corresponds to NovaScan Variable #5). Higgins et al. (1975) demonstrated that a 12-hour shift in the wake-sleep cycle of 15 male participants (ages 20 to 28) produced deficiencies in individuals' multiple tasks performance (which corresponds to NovaScan Variable #3). Luna et al. (1997) found that Air Force controllers reported greater amounts of confusion (which corresponds to NovaScan Variable #4) and less vigor on night shifts than when on evening or day shifts of a rapidly-rotating schedule.

The difference between this study and the previously cited research is that this study determined objective measures by NovaScan in a natural setting for all the variables tested, whereas, the previous research has only reported subjective ratings in natural or laboratory settings, or objective ratings determined in contrived laboratory environments.

Assumptions

It was assumed that the participants recruited for this study had no significant cognitive differences and that they were free of any attention or learning decrements not related to dysrhythmia. Air traffic controllers possess unique cognitive skills and abilities. These cognitive attributes become unique to controllers through a weeding-out process and through cognitive training. Controllers undergo pre-employment cognitive and psychological testing which has been developed to eliminate individuals who do not possess the necessary mental attributes required of air traffic control work in general. The training that controllers obtain continues to eliminate individuals who do not possess the particular skills and abilities that are required, and to develop those skills and abilities in the individuals who do possess them. The cognitive variables that were investigated in this study are some of the same cognitive variables that are developed through controller training.

Summary

In the previous pages, the problem statement and need for the study were identified. The problem is that, each year many controller errors lead to aircraft accidents. This study is necessary because many air traffic controllers work rotating shift work and are susceptible to the adverse effects of circadian dysrhythmia, a condition which causes decrements in alertness and performance ability. These decrements could be a factor in controller learning deficiencies during training sessions, and/or deficiencies in situation awareness during dynamic air traffic control situations. In order to address these factors, the hypotheses to be answered by this study were proposed, and the underlying limitations, delimitations and assumptions of the investigation were discussed.

Chapter two will discuss the related literature and research findings concerning circadian rhythms and circadian dysrhythmia. This chapter will also discuss shift work and the different types of shift systems used in industry and air traffic control facilities. Following this is a review of literature concerning the decrements in alertness and performance caused by circadian dysrhythmia. Finally, a review of the literature concerning circadian rhythms and learning is presented.

CHAPTER 2
RELATED LITERATURE

Circadian Rhythms

Circadian rhythms are cycles which occur on a daily basis, but they are only part of a larger system of rhythms.

> We live in a universe of rhythms. Our galaxy rotates once every 200 years. Sun spots occur every 11 years and tides every 12 1/2 hours. But the most significant rhythm for the inhabitants of this planet is the earth's rotation every 24 hours. (Hawkins, 1987, p. 51)

Cycles which are shorter than 24 hours are called "ultradian", and cycles which are greater than 24 hours are called "circamensual" (Adan, 1993, p. 146). Organisms which live on our earth have evolved within this universal, cyclic environment.

Human circadian rhythms are both physiological and psychological in nature. The study of physiological (or biological) rhythms is known as chronobiology, and the study of psychological (and behavioral) rhythms is known as chronopsychology.

The biological rhythms include such variables as hormone production, body temperature, organ functioning, immune system cycles, blood cell functioning, and stomach and intestinal tract functioning (U.S. Congress, Office of Technology Assessment, 1991).

Each of these variables displays a daily cycle which has its own peak (acrophase) and low point (nadir).

Psychological and behavioral rhythms include such variables as alertness, performance, and the habits of an individual. These rhythms also display an acrophase and nadir. It has been demonstrated that short-term memory and long-term memory have separate rhythms which peak at different times of the day (Folkard & Monk, 1980).

Some psychological/behavioral rhythms, such as digit summation ability and short-term memory, and the biological temperature rhythm tend to correspond and to influence one another. Other psychological/behavioral rhythms such as alertness and long-term memory tend to run in a staggered opposition to the temperature rhythm. The alertness rhythm, for example, tends to peak between 10 a.m. and noon, while the temperature rhythm tends to peak between 4 p.m. and 8 p.m. (Hawkins, 1987; U.S. Congress, Office of Technology Assessment, 1991).

Circadian rhythmicity stems from two causes, "an endogenous cause, the internal clock, and an exogenous cause, the rhythmic environment and habits of the individual" (Folkard et al., 1985, p. 33). By the late 1970s, it had become clear that most of the body's rhythms are controlled by processes deep within the brain (Hawkins,

1987). Here, the most powerful of the entraining agents (or zeitgebers), the cycle of light and darkness, is detected through the eyes and influences the body's visceral system and other cyclic functions. Other rhythms, however, like that of the body temperature rhythm, are controlled elsewhere and remain the object of further investigation. Activities, such as meal time, and physical and social activity, also serve as entraining agents (Hawkins, 1987).

According to Mistlberger and Rusak (1989), psychological and biological rhythms have an internal relationship with time-of-day restraints. Human behavior and physiological processes demonstrate a temporal structure that matches the 24-hour day-night cycle. The most obvious daily cycle that humans experience is the cycle of sleep and wakefulness. Similarly, a myriad of bodily functions, including endocrine secretions, body temperature regulation, sensory processing, and cognitive performance, demonstrate a 24-hour rhythmicity (p. 141).

Historically, circadian rhythms were ascribed to environmental cues associated with the solar day, but a large number of studies have confirmed that daily rhythms in a wide variety of species, including humans, persist under constant environmental conditions. Because of this, it is acknowledged that daily rhythms are generated

internally by the organism and are not simply passive responses to environmental stimuii (p. 142).

In the absence of environmental cues, daiiy rhythms are said to be "free-running." Free-running rhythms approximate the 24-hour day, but not exactly. This periodicity (time required for one complete rhythm cycle) is termed "circadian" (circa = about, dies = day). Humans who are kept in isoiation without time cues display a 25-hour sleep-wake cycle. Sleep onsets begin to occur at 25-hour intervais instead of the normal 24-hour day-night intervais experienced in ordinary society. Under this free-running cycle, as it is termed, humans go to sleep later each day than they would under normai circumstances.

Free-running sleep-wake cycles vary among species from about 23 to 26 hours and are modified by factors such as ambient light intensity, or hormone production. But, the fact that free-running cycles differ from the normal 24-hour cycle is strong evidence that circadian rhythms are generated internally, and are not simply responses to daily 24-hour time cues. In fact, individuals of the same species recorded under laboratory conditions in adjacent cages demonstrate different periodicities which cause the animals to slowly drift apart from one another, while sharing the same environment (Mistlberger & Rusak, 1989, p.142).

> Other evidence that supports the idea that circadian rhythms are endogenousiy generated includes the demonstration that they can be modified by seiective breeding (Bunning, 1973) and gene mutations (Konopka, 1980) and that they deveiop normaiiy in successive generations of organisms kept in iight or dark (Aschoff, 1960; Davis, 1981). Circadian rhythms are thus innate, rather than iearned or imprinted, phenomena. Virtually all researchers now agree that circadian rhythms are the products of an internal biological clock mechanism.
> (Mistlberger & Rusak, 1989, p. 142)

There are several recognized environmental influences which serve as entraining agents to rhythmic cycles. Many organisms, including humans, find it adaptive to restrict rest and activity to specific times of the day in order to take advantage of environmental conditions which are optimal for various functions. By internalizing the controlling mechanism for initiating rest and activity periods, organisms are able to anticipate environmental events, such as temperature, humidity, and changes in light intensity associated with morning and nightfall, so that they may prepare accordingly. Organisms accrue advantages by phasing their behaviors with these environmental events, while anticipating them rather than merely responding to their constraints. Therefore, some mechanisms must exist which ensure that the internal timing device of an organism maintains a synchronous phase relation to the environment (Mistlberger & Rusak, 1989, p. 146).

Light is, as expected, a universal zeitgeber (entraining agent) for the activity-rest cycle displayed by most organisms, from single-celled life forms through mammals. "A recent case report indicates that circadian rhythms of body temperature and endocrine variables in an elderly woman could be shifted by appropriately timed exposure to bright light, independently of the timing of sleep-wake states" (Mistlberger & Rusak, 1989, p. 145).

There are also several non-photic stimuli that appear to entrain circadian rhythms. The timing of meals influences circadian cycles through the anticipatory activity associated with mealtime in organisms. This effect is very evident in experiments with rats. Arousal states can also trigger the circadian timing system.

> Simple handling of white-footed mice (Rawson, 1960) or changing the litter of hamsters (Mrosovsky & Hallonquist, 1986) can phase shift free-running rhythms, suggesting that even brief arousals may have feedback effects on circadian timing. In humans recorded in temporal isolation, a daily "anchor sleep" (4 h of forced bed rest at a fixed time every 24 h) can apparently synchronize daily rhythms (Minors & Waterhouse, 1981), but whether this synchrony is related to anchor sleep per se or daily LD (light-dark cycle) or food intake schedules is unclear. (Mistlberger & Rusak, 1989, p. 146)

Social cues are another well-known entraining agent in many species, including humans, however, they are not universally effective. It has been demonstrated that some blind humans display free-running sleep-wake cycles in diurnal environmental conditions.

These individuals are not synchronized by society's social cues. Just how social cues influence circadian timing is not known, but the social cues' effects on arousal states are probably the necessary mediators for the relationship (Mistlberger & Rusak, 1989, p. 146)

Dinges (1989) describes how sleep is affected by the circadian timekeeping system. According to Dinges, the daily sleep-wake cycle serves to organize wake behavior into discrete temporal units and to coordinate and synchronize the internal timing of many biological rhythms. We cannot know for sure whether early mammals were diurnal or nocturnal, but there is little doubt that primates, and homo sapiens in general, evolved as diurnal species who sleep primarily at night (p. 153).

Dinges (1989) states that recent sleep research shows us that the infrastructure of sleep itself might depend less on sleep and more on a rhythmic process common to sleep and wakefulness. This sleep-wake cycle is also affected by sometimes contrasting factors.

> To begin with, unlike many other physiological parameters such as body temperature, the sleep cycle is not a unitary process that varies along a continuum; sleep is distinct from wakefulness, sleep onset contrasts with sleep offset, and there are different stages of sleep. Even more problematic, however, is the fact that among our species, the initiation and termination of sleep are influenced as much by sociopsychological factors as by endogenous biological factors. (p. 156)

According to Dinges (1989), research also indicates that the onset and offset of sleep and wakefulness display a cycle which reflects the biological temperature cycle. The temperature cycle reaches its low point at about 4 am and its acrophase at about 4 pm. As temperature rises, sleep offset generally occurs, and as temperature decreases, sleep onset generaiiy occurs. The probability for sleep onset and sleep offset over a 24-hour period in a normal diurnal cycle follows a pattern:

1. (01:00-07:00) sleep onset probability high; sleep offset probabiiity low.
2. (07:00-13:00) sleep onset probability low; sleep offset probability high.
3. (13:00-19:00) sleep onset probability high; sleep offset probability high.
4. (19:00-01:00) sleep onset probability low; seep offset probability low.

This pattern of sleep onset/offset propensity seems to indicate that there are two periods during the cycle where sleep onset is desirable.

> Although nocturnal sleep episodes appear in phase with the circadian nadir in the endogenous core temperature cycle, naps occur across the typically broad peak (variable acrophase) of the temperature cycle, suggesting the possibility of a secondary sleep propensity approximately 180 degrees out of phase with the circadian cycle in body temperature (Broughton, 1975; Dinges et al., 1980). (Dinges, 1989, p.155)

Sleep research indicates that long sleep episodes occur when subjects begin sleep just after the acrophase of the temperature cycle in the afternoon. If a subject begins sleep at this time, there is a propensity to sleep until the temperature cycle is on the rise again the next morning. In a normal diurnal cycle with two sleep episodes, research indicates that, "longer sleep began just prior to the temperature minimum, whereas shorter sleep (naps) occurred near the temperature maximum" (Dinges, 1989, p.159).

The time of sleep onset in humans does not always follow the natural cycle of tendencies for sleep because chronobiological influences on our sleep cycles are often superseded by the sociopsychological factors in our daily lives. Sociopsychological cues, such as human contact and signals of activities to be carried out, are important influences on the human sleep-wake cycle. Because of this, these factors are thought to play a major role as zeitgebers for the variation in the sleep-wake cycle. However, problems may arise from social zeitgebers which would not occur from physical zeitgebers, such as the light-dark cycle. Social zeitgebers can easily cause a person to attempt a major, abrupt change in the sleep-wake cycle before internal circadian processes, such as the temperature rhythm, are able to adjust (Dinges, 1989, p. 159).

The circadian system is very complex and it interacts with the physiology and psychology of humans and other species. According to Mistlberger and Rusak (1989), circadian organization is a pervasive, integral component of mammalian physiological systems, which affects behavior in a great many ways. The underlying mechanisms of this influence are themselves complex, involving a hierarchy of oscillators that interact with each other and with other regulatory systems. The circadian system is acutely sensitive to photic cues in the environment which directly influence the dominant pacemaker of the system, however, behavior may be equally affected by other environmental variables, by influencing other elements of the oscillatory hierarchy (p. 150).

Circadian Dysrhythmia

Circadian dysrhythmia is a condition which describes the internal disassociation of the biological and/or psychological rhythms of an individual (Hawkins, 1987). As stated earlier, this condition is primarily the result of transmeridian flight (Winget et al., 1984) or rotating shift work (Folkard & Monk, 1979).

Several researchers have shown that many circadian variables are affected by acute shifts in routine (Akerstedt & Gillberg, 1980; Gander et al., 1989; Higgins et al., 1975; Monk et al., 1988; Saito et al., 1992). Most of these studies indicate that, once circadian

rhythms are desynchronized, at least 7 days to several days are required for resynchronization to occur. Until resynchronization does occur, an individual will experience biological and psychological decrements which are reflected in psychomotor and cognitive performance (U.S. Congress, Office of Technology Assessment, 1991).

Higgins et al. (1975) conducted a study involving 15 male participants (ages 20 to 28) in order to determine the effects of a 12-hour shift in the wake-sleep cycle on physiological and psychological circadian rhythms. The results of this study indicated that the quantity and quality of sleep did not change to a significant degree after the sleep cycle was altered. The subjective fatigue index, likewise, indicated that the total fatigue for the awake periods was not significantly changed. However, the times of greatest fatigue within days were altered, and complete reversal of the daily pattern required nine days.

The physiological parameters which made the most rapid response to stress were also the same parameters which required the shortest period of time to rephase after the shift in routine. The physiological parameter requiring the shortest rephasal time was heart rate, followed in sequence by norepinephrine, epinephrine, potassium, sodium, internal body temperature, and 17-ketogenic steroids.

Performance data based on the Civil Aeromedical Institute Multiple Task Performance Battery suggest that (1) diurnal variation was present during the preshift period, (2) performance decrements occurred on the day of the shift following the short sleep period, (3) performance rated relatively high for most of the day, but became poor toward the end of the shift for the first three days following the shift in routine, (4) performance on the fourth through the sixth post shift days rated at or above average, with relatively small variations among the five test sessions per day, and (5) performance on the seventh through ninth post shift days was below average for the experiment and demonstrated evidence of a return to a diurnal pattern, which reflected the post shift sleep-wake cycle (Higgins et al., 1975, p. 1).

According to Higgins et al. (1975), the implications of the findings cited in this study include the following:

> (1) individuals making a 12-hour alteration in the wake-sleep cycle should not perform critical tasks during the first awake period following the change. (2) After the first full sleep period following the change, subjects appeared to perform well even though the physiological and biomedical parameters measured were still adjusting to the change. (3) For the first week following the change in the wake-sleep cycle, individuals should not work longer than 8 hours continuously because performance deteriorates after that time. After the change, subjects appeared to fatigue more rapidly toward the end of the awake period than they did normally. This effect was evident for several days after the change. (p. 23)

Monk et al. (1988) also conducted a study of the affects of an acute shift in routine with 8 middle-aged male participants. In this study, researchers induced jet lag in a laboratory setting by advancing the routine of the participants by 6 hours. As stated earlier, the effects of jet lag would be the same as those experienced by changes in routine due to changing work hours in shift work.

The eight participants in this study were kept in temporal isolation for the 15-day experiment. After the participants were entrained to their own habitual routines for five days, each participant experienced an acute 6-hour phase advance in routine which was brought about by a shortening of the sixth sleep episode. The participants were then held to the new phase-advanced routine for the ten remaining days of the experiment.

Following the shift in routine, the participants demonstrated significant symptoms of jet lag which were observed in mood, performance efficiency, sleep, and physiological temperature rhythms. Some of the variables, such as temperature phase and percent rapid-eye-movement sleep, showed a monotonic recovery pattern. However, other variables, such as actual sleep duration, percent slow-wave sleep, motivation loss, and subjective sleepiness, demonstrated a zig-zag recovery pattern, which suggest the interaction of two competing processes (p. 703).

The results of this study indicated that the disruption in the amplitude of the circadian temperature rhythm was the most dramatic circadian effect, and this effect lasted for several days following the phase shift.

> For instance, even 6 days after the phase shift, the mean change in amplitude of each subject's temperature rhythm was 26% below his own baseline level. This reduction in amplitude may bespeak a desynchrony within the circadian system. Normally, the component parts of the circadian system are in the correct phase reiationship to each other, combining to produce robust, well-defined circadian rhythms. After an acute shift in routine, however, these component parts do not adjust their temporal orientation at the same rate, and appropriate phase relationships are thereby lost. This has been referred to as "internal dissociation," a state shown to be associated with impairments in mood and performance efficiency (Wever, 1975; Wever, 1979). (p.708)

Among the variables showing a zig-zag recovery function were the subjective alertness/sleepiness rhythm and the motivation loss. Some of the post-shift days indicated worse effects than those on the day immediately preceding them (p. 709).

Akerstedt and Gillberg (1980), in a study that they conducted with six male subjects in temporal isolation, demonstrated that sleep termination may be closely related to the sleepiness/alertness rhythm. In this study, sleep times were displaced to seven different times of the day through a rate of one sleep condition change per week. The length of each sleep episode varied according to when it

began. The shortest sleep episodes occurred when sleep onset began in the morning, and the longest sleep episodes occurred when sleep onset began in the evening. Sleep termination times were related to specific points on the sleepiness/alertness rhythm.

Gander et al. (1989) conducted a study involving air crews of P-3 aircraft in order to determine the adjustment of sleep and the circadian temperature rhythm after flights across nine time zones. In this study, researchers investigated both westward flight (phase-delay variation) and eastward flight (phase-advance variation). The study involved nine Royal Norwegian Air Force volunteers operating P-3 aircraft during flights across nine time zones. The variables monitored during the flight included each participant's sleep-wake pattern and circadian temperature rhythm. Each participant recorded his own sleep and nap times, rated nightly sleep quality, and personality inventories, while rectal temperature, heart rate, and wrist activity were continuously monitored.

Adjustment after the return eastward flight was slower, as compared to adjustment after the westward flight, for the readjustment of sleep timing to local time. The eastward flight also produced greater interindividual variability in the patterns of adjustment of sleep cycles and temperature rhythms. One of the participants even exhibited a 15-hour phase-delayed

resynchronization, rather than a phase-advanced resynchronization, of the temperature rhythm after the eastward flight. The interindividual differences in adjustment of the temperature rhythm correlated with some of the personality measures, but it was found that larger phase delays in the temperature rhythm (as measured on the fifth day after westward flight) were exhibited by participants who were rated extroverts, and smaller phase delays were exhibited by evening types (p. 733).

In this study, Gander et al. also found that all of the subjects showed clear phase delays in the sleep cycle for both sleep onset and sleep offset on the westward flight (or phase delay), but that there was greater intersubject variation in the timing of sleep following the eastward flight (or phase advance). The slower adaptation and adjustment to eastward flight was due to the variable recovery methods of the circadian rhythms. After eastward flights, some of the circadian rhythms tend to resynchronize by delaying, while other rhythms advance. It appears that extroverts tend to adapt more rapidly to the delay shift, probably because they are more exposed to the social routine in the new time zone (p. 742).

Wright et al. (1983) studied 81 male soldiers (ages 18-34) for five days before and five days after an eastward deployment across six time zones. Commonly reported jet lag symptoms of tiredness,

sleepiness, weakness, headache, and irritability appeared in the majority of the subjects. While most of the symptoms had disappeared or diminished by the fifth day in Germany, tiredness, sleepiness, and irritability continued.

The cardiorespiratory responses and the perception of effort during treadmill exercise were completely unaffected by the conditions experienced by the participants in this study, however, other variables were affected.

> While isometric strength of upper body, legs, and trunk was unchanged, dynamic strength of arms was significantly reduced after arrival in Germany in two out of three groups at the slow contraction speed and even more dramatically in all groups at the fast velocity. These findings are suggestive of adverse jet-lag effects on some aspect of muscle contractile capabilities, most likely motor control and fiber recruitment. Dynamic arm endurance declined in a comparable fashion. Complete recovery of arm strength and endurance did not occur within the first 5 d after deployment. (p. 136)

Saito et al. (1992) conducted a study of the gradual adjustment of circaseptan-circadian blood pressure and heart rate rhythms of two adults (36-year-old male; 32-year-old female) and two children (6-year-old boy; 6-month-old boy) after an eastward flight which advanced local time by 9 hours. Circadian rhythms are daily rhythms of about 24 hours, whereas, circaseptan rhythms are rhythms of about 7-days duration.

The results of this study indicated that gradual changes continued for four weeks. The adult male's blood pressure rhythm delayed in order to recover, while the adult female's rhythm advanced. Approximately four weeks were needed for adjustment of circaseptan rhythms in the two adults, but it only took two weeks in the boys.

The adjustment of rhythms during childhood appears to be faster not only with circaseptans, but also with circadian rhythms. The results also indicated that the heart rate rhythms adjusted more rapidly than the blood pressure rhythms, and that the boys' circadian rhythms adjusted faster than the adults' circadian rhythms. The older boy's rhythms adjusted more rapidly than the younger boy's rhythms. "In the younger boy, the adjustment showed great lability which might suggest that the circadian rhythmicity is still developing and immature" (p. 73).

The National Aeronautics and Space Administration (NASA) has developed the NASA Ames Fatigue Countermeasures Program to compile research concerning fatigue caused by such factors and to develop countermeasures. According to Rosekind (1993),

> More than a decade of research at NASA Ames on pilot fatigue, sleep, and circadian rhythms has identified new insights into crew fatigue. Some basic findings include:
> * Sleep loss and circadian disruption from long-haul flight operations can result in fatigue, increased sleepiness, and reduced performance.

* While on short-haul trips for 3 to 4 days, pilots take longer to fall asleep, sleep less, awake earlier, and report lighter and poorer sleep compared to pre-trip sleep patterns.
* Pilots generally report feeling less well during extended duty periods, but helicopter pilots on short-haul flights for 4 to 5 days are far more likely to report headaches and back pain than are commercial short-haul fixed-wing pilots, probably due to the physical environment of the helicopter flightdeck.
* Off-duty time overstates the time available for sleep.
* Regulation of duty hours should be considered, much like flight hours.
* Rest periods should occur at the same time on trip days or progressively later across days.
* On layovers, experienced international flight crews sleep efficiently at selected times or sleep less efficiently but longer than normal with a preference for sleeping during local night.
* However, despite efficient or longer sleep during layovers, the circadian system is unable to resynchronize and quickly adapt to rapid, multiple time zone shifts.
* A brief in-flight nap is an acute in-flight safety valve to improve performance and alertness on long-haul flights, but naps do not affect the cumulative sleep debt in most crewmembers. (p. 24)

Age has also been shown to have an effect on individuals' circadian rhythms. Research by Keran and Duchon (as cited in U.S. Congress, Office of Technology Assessment, 1991, p. 95) has demonstrated that individuals over the age of 45 may begin to demonstrate the effects of dysrhythmia and may have trouble sleeping at night.

Shift Work

Overview

The term "shift work" has many meanings and varies according to which author or context is used as reference. According to Akerstedt (1988),

> Shift work usually refers to an arrangement of work hours that uses two or more teams (shifts) to cover the time needed for production. Whereas two-shift work usually covers only the daylight hours, three-shift work also covers the night. Shifts are often changed at ~0600 h, 1400 h, and (if a night shift is included) 2200 h, although many companies employ earlier or later times. In Europe, the teams usually rotate between the shifts, whereas in the United States, assignment to a certain shift is often permanent, at least for a considerable time, before seniority allows transfers to another shift. Permanent night work, the watch system at sea, and roster work are other varieties of work hour arrangements. The latter (roster work) is similar to conventional shift work but is somewhat more irregular and "customized" to particular needs, usually in the service sector. For lack of better terminology we will refer to all these types of work hour systems as shift work. (p. 17)

Individuals who work rotating shift work, in most cases, are almost constantly subjected to negative physiological and psychological effects that are similar to those experienced as a result of jet lag. The severity of the condition depends upon the type of rotating schedule that the individual works and the number of hours worked during each shift.

Schedules which rotate on a weekly basis can cause biological rhythms to desynchronize, as they try to adjust to each new routine

each week. On the other hand, schedules which rotate rapidly, covering all shifts each week, allow biologicai rhythms to remain diurnal, but can cause desynchronization of the psychological/behavioral rhythms, as the habits and daily routine of the individual adjust to accommodate each new work period during the week (Folkard et al., 1985; Paley & Tepas, 1994; U.S. Congress, Office of Technology Assessment, 1991). Researchers have indicated that sleepiness and fatigue which result from shift work are detrimental to safety in many occupations (Akerstedt, 1988), and that individuals who work shift work never adjust to it, even after several years (Akerstedt & Kecklund, 1991).

Work Schedules

Shift work takes a variety of configurations in industry, government, and the military, and it also varies according to the tradition of the country or occupation in which it appears. "It has been estimated, however, that approximately one-fourth of the working population in industrialized countries is employed on some kind of shift work system" (Akerstedt, 1988, p. 18).

The different types of rotating schedules in shift work each have their own advantages and disadvantages. As previously stated, Folkard et al. (1985), and Monk (1986) indicate that rapidly-rotating shift systems allow the endogenous circadian system to remain

diurnal, whereas, weekly-rotating systems desynchronize these physiological circadian rhythms. The rapidly-rotating systems are also advantageous in that they do not allow a sleep debt to accumulate because the number of day sleeps is less continuous than with the weekly-rotating systems. However, decrements in alertness and increased fatigue are reported by workers under both systems, indicating that workers' psychoiogical rhythms are negatively effected, probably due to the changes in routine experienced under both systems.

Many researchers once thought that permanent night work might be more conducive to a more efficient adjustment to sleepiness. But, Folkard et al. (1978) found that the rated alertness of permanent night nurses remained diurnal, or day-oriented, except for a minor blunting of the steep fall of the alertness curve during the night shift. Other researchers (e.g., Dahlgren, 1981; Patkai et al., 1977) indicate that sleepiness in permanent night work appears to be phase delayed and exhibits a peak towards the end of the shlft.

Melton and Barlanowicz (1986) described the different models of shift work, such as the phase-advanced 2-2-1 (2 evenings, 2 days, 1 midnight) schedule, and its opposing phase-delayed 1-2-2 model, in order to explain why certain shift work models are deslred by workers. They indicated that the 2-2-1 rotation is preferred by

many controllers because it allows for longer intervals between work weeks. About an 80-hour break, or 48% of the 7-day week, is realized between work weeks with this shift rotation. This is accomplished by compressing 40 hours of work into an 88-hour period, with short intervals between each shift change (quick-turn-arounds). Quick-turn-arounds usually take the form of an 8-hour break between shifts.

A phase-delayed 1-2-2 schedule expands the work week with longer periods of 18 to 22 hours between shifts (slow-turn-arounds). These schedules start off with the midnight shift and progress through later shifts over the week, ending on the evening shift. The off-duty period at the end of the week is usually about 48-hours duration.

In the case of either the 2-2-1 or the 1-2-2 rotation, however, all shift schedules require 40 hours of work in a 5-day period with 8 hours work per shift. It is noteworthy that the expanded 1-2-2 rotation is not known to be in use in any industrial setting. It seems that workers will accept almost any work schedule that will provide a long break at the end of the work week. Some nuclear power plants operate on 12- and 16-hour shifts. Many police officers work 12-hour shifts for 4 days, and then have 4 days off. One of the perquisites (perks) of seniority in shift work is choice of work

schedule, or time off. Workers more often bargain for time off rather than for monetary compensation (p.3).

Meiton and Bartanowicz (1986) also described the weekly-rotating schedule. This work schedule, the straight five pattern, allows individuals to work the same shift for five days, have 48 hours off, and then begin the next, usually later, shift. Research by the Federal Aviation Administration, and others, has demonstrated that the five mid watches in a row is the wrong type of shift rotation to use, from the standpoint of circadian rhythmicity. The five straight mids leads to accumulated sleep loss and fatigue because day sleeps are cut short due to noise levels, light intensity, and the phase of the circadian temperature rhythm and other physiological rhythms. The sleep that is attained is mainly fatigue-induced sleep, which is usually brief and inadequate (p. 5).

According to Akerstedt (1988), schedules which rotate should do so with consideration being given to the direction of rotation, if they are to be beneficial to the health and performance of the worker.

> Another important aspect of the shift schedule may be its direction of rotation. Since the free-running period of the human sleep/wake cycle averages 25 h, and since it can be entrained by environmental time cues only within 1-2 h of the free-running period, phase delays are easier to accomplish than phase advances (Czeisler et al., 1980). For the rotating shift worker, this implies that schedules that delay,i.e., rotate clockwise (morning-afternoon-night) should be preferred to those that rotate counterclockwise. However, there have been

> very few practical tests of this theory, particularly in relation to sleepiness. Still, Czeisler et al. (1982) have demonstrated that a change from counterclockwise to clockwise rotation, together with a change from 7-day to 21-day rotation, improved productivity and wellbeing in three-shift workers. Orth-Gomer (1983) found that a change in the same direction in police officers on rapid (1-day) rotation reduced blood pressure and improved wellbeing. (p. 27)

McAdaragh (1995) conducted a study of 997 air traffic controllers' (ATC's) work schedules from randomly selected ATC facilities in order to determine what types of schedules controllers tend to work. It was determined that 45% of the controllers were working either phase-advance, compressed schedules of the 2-2-1 variety, or an alternate work schedule which even further compresses the work week into four 10-hour days. Only 24% of the controllers were working straight days or straight evenings, whereas, the remaining 31% were working a variety of none-standard rotating schedules. None of the controllers were working the 1-2-2 phase-delayed schedule or anything like the schedule proposed by Czeisler, which was reported to improve the production and wellbeing of rotating shift workers.

Sleepiness

According to the U.S. Congress, Office of Technology Assessment (1991), shift work can cause a variety of negative psychological and physiological effects. This is attributed to the fact that the shift

worker must fight both the natural, diurnal trend of physiological circadian rhythms, and the dominant sociocultural attitudes. Because of this, there are three sources of stress for the shift worker: (1) disruption of circadian rhythms, (2) disruption of sleep and fatigue, and (3) social domestic disturbances (p. 89).

The Office of Technology Assessment also indicates that disruptions to circadian rhythms that interact with loss of sleep and fatigue can also affect health and performance. "Sleepiness is the inclination to sleep, whereas fatigue is weariness due to physical and mental exertion. It is possible to experience one without the other, but both, either alone or in concert, can have deleterious effects" (p. 87).

Sleepiness (often referred to as fatigue) has been measured through a variety of methods. Traditionally, sleepiness was measured via simple category rating scales or other simple rating scales. Later methods, using the electroencephalograph (EEG) and the electrooculograph (EOG), attempted to achieve more objective measures.

According to Akerstedt (1988), the first attempt to quantify objective physiological measures of sleepiness was the Multiple Sleep Latency Test (MSLT). This test expresses sleepiness as the time it takes for the EEG/EOG signs of sleep to appear in a subject with eyes

closed. This test, and variations of it, remains the only standardized clinical method of measuring sleepiness. However, it is difficult to use outside of well-controlled laboratory, or laboratory-like, environments, and it cannot reflect momentary fluctuations of sleepiness.

> Nevertheless, it appears that other EEG/EOG parameters may be used for the description of momentary fluctuations of wakefulness/sleepiness. Thus vast amounts of data support the proposition that increased Alpha and Theta activity in the EEG, and also slow eye movement (SEM) activity, are closely correlated with both subjective and behavioral sleepiness (Daniel, 1967; O'Hanlon & Beatty, 1977; Torsvall & Akerstedt, 1984; Akerstedt et al., 1984; Lecret & Pottier, 1971; O'Hanlon & Kelley, 1977;Torsvall & Akerstedt, 1987). In a record study (Torsvall & Akerstedt, in press), we tried to experimentally quantify the EEG/EOG changes that characterize severe sleepiness, i.e., the level of sleepiness at which drowsiness prevents interaction with the environment and the individual dozes off. We found after spectral analysis that increases of ~500 and 200% in the power density of alpha and theta activity, were critical (compared with the values at normal alertness). Furthermore, field studies have demonstrated that EEG/EOG-based monitoring of sleepiness is also feasible in completely ambulatory subjects under their normal work/leisure/sleep conditions (Torsvall & Akerstedt, 1987; Torsvall et al., unpublished observations). (Akerstedt, 1988, p. 18)

Most studies concerning sleepiness in shift work derive, as indicated earlier, from subjective questionnaire studies. Several of these studies, including Wyatt & Marriot, 1953, Thiis-Evensen, 1958, Mott et al., 1965, Menzel, 1962, Andersen, 1970, and Akerstedt & Torsvall, 1978 (as cited in Akerstedt, 1988, p. 18) indicate that shift

workers on the whole report greater fatigue than do day workers. This fatigue is usually greatest on the night shift, intermediate on the morning shift, and hardly appears at all on the evening shift.

A record study by Torsvall and Akerstedt (as cited in Akerstedt, 1988) used both subjective, self-report measures of sleepiness, and objective EEG/EOG ratings. The results of this study indicates that individuals perceive sleepiness coming before it becomes manifested on objective ratings. "It therefore appears that sleepiness is perceived by the individual well before he or she is overcome by sleep. Thus, one should be able to use subjective sleepiness as a signal or warning that involuntary sleep might ensue" (Akerstedt, 1988, p. 22)

Akerstedt & Torsvall (1978) used an experimental design which showed that reported fatigue increased upon entering shift work, and decreased upon leaving it. Also, Akerstedt et al. (1983) determined that sleepiness has been severe enough to have resulted in actual incidents of individuals falling asleep during the night shift. These studies have since been duplicated by other researches.

Folkard and Condon (1987) demonstrated a somewhat unusual manifestation of night shift sleepiness reported by night shift nurses which came to be known as "night shift paralysis." This is a rare phenomenon which seems to occur as a function of sleep loss (due to

shift work) and takes the form of an inability to react to stimuli which should normaiiy elicit a response. Nurses may not react to a call from a patient or a question from a colleague, for example.

A similar study by Folkard and Condon was later conducted with air traffic controllers. This study was designed to examine the possibility that night shift paraiysis may be a problem in this group. The sample included 435 air traffic controllers from 17 different countries, who were working a variety of work schedules. The incidence of paralysis was found to be influenced by four main factors which, in turn, affect the workers' level of sleep deprivation and sieepiness. These factors included (a) the time of night, (b) the number of consecutive night shifts, (c) the requirement to work both a morning shift and a night shift starting on the same day, and (d) individual differences in flexibility of sleep habits. "These results suggest that the incidence of this paralysis may Indeed prove to be a useful 'critical incident' for comparing the level of sleep deprivation associated with different shift systems or individuals" (Folkard & Condon, 1987, p. 1353).

Foikard and Condon also described the relationship between the alertness cycle and the sleep/wake cycle, and how partial sleep deprivation occurs as a result of shift work.

> It is well established that subjectively rated alertness shows a marked circadian (about 24 h) rhythm that is at least partially

> independent of the normal sleep/wake cycle (Folkard et al., 1985), and that alertness is low in the early hours of the morning. Similiarly, there is good evidence that the duration of day sleeps taken between two successive night shifts is considerably shorter than the duration of normal night sleeps (Knauth et al., 1980). Thus there will be a cumulative partial sleep deprivation over successive night shifts which could account for the increased incidence of this paralysis on the second or subsequent night shift. Further, there is also evidence that night sleeps preceding a morning shift are shorter than normal ones (Knauth et al., 1980). Finally, rigid sleepers, and especially those who are also evening types, are less likely to be able to sleep successfully prior to a night shift. (Folkard & Condon, 1987, p. 1361)

As stated earlier, Pilcher and Huffcut (1996) found, through a meta-analysis of sleep deprivation studies, that sleep deprivation has its greatest effect on mood with a lessor effect on cognitive performance and motor performance, respectively. They also determined that partial sleep deprivation (sleep loss which occurs whenever there is a reduction in the usual amounts of sleep obtained in a 24-hour period), rather than long-term or short-term sleep deprivation, has a greater negative effect on mood and cognitive performance. This is important to shift workers, because partial sleep deprivation is one result of working irregular or rotating schedules. The condition which occurs due to partial sleep deprivation associated with shift work has been termed "shift-work insomnia" (Akerstedt & Kecklund, 1991, p. 509).

Other researchers have determined that irregular sleep schedules are responsible for daytime sleepiness. As stated earlier, Manber et al. (1996) demonstrated that, even when a full-night's sleep is achieved by both groups, individuals who sleep at irregular schedules report a lessor amount of alertness and a greater amount of sleepiness during the day than do individuals who sleep at reguiar sleep-wake schedules. Billiard et al. (1987) support this conclusion with a study involving French military draftees. These researchers found that sleep difficulties and irreguiar sleep-wake schedules were major factors contributing to excessive daytime somnolence in young men between the ages of 17 and 22 years of age.

One study conducted by the Federal Aviation Administration's (FAA's) Civil Aeromedical Institute (CAMI) compared a group of air traffic controllers on a rapidly-rotating schedule with a group of controllers on a weekly-rotating schedule. The results indicate that, during the work week, controllers working the rapidly-rotating system acquired less sleep than the controllers working the weekly rotating system, but that this sleep deficit diminished when days off were taken into consideration. The controllers on the rapidly-rotating system caught up on their sleep on their days off. But, in general, both groups reported similar complaints. "Fatigue, weakness, and somnolence were the most frequent on-duty

complaints given by controllers on the mid shift, followed by those same complaints in decreasing order of frequency on day and evening shifts" (Saldivar et al., 1977, p. 5).

Individuals who work rapidly-rotating schedules have their sleep cut short during day sleep primarily because of two reasons. First, there are higher noise levels usually present in the morning hours after night work is ended and the normal daytime activities of society begin. Second, individuals attempting to sleep in the mid- or late-morning hours are also attempting to sleep while their diurnal temperature rhythm is rising. Normally, sleep onset occurs in the evening, when the body temperature rhythm is on the decline. Day sleep is, therefore, shortened even if a sleep deficit exists. This in turn helps lead to sleepiness, especially on the night shift. "Sleepiness occurring during night work seems to be the result of a combination of influences: the circadian trough of the alertness rhythm, and sleep loss/time awake" (Akerstedt, 1988, p. 26).

It has been estimated that most individuals who work shift work never adapt to it. Akerstedt and Kecklund (1991) completed a two-year study of rapidly-rotating shift workers at a paper mill. "The results suggest that sleep has a traitlike character, even when occurring at daytime after a night shift. This, therefore, suggests that

shift work insomnia is a persistent problem--those afflicted tend to remain so for some time" (p. 509).

According to a review by the U.S. Congress, Office of Technology Assessment (1991),

> Some researchers (Folkard et al., 1985; Knauth et al., 1981) maintain that, regardless of rotation length, complete realignment of circadian cycles never actually takes place in shift work due to the competing influences of cues in the society telling workers that they are on an abnormal schedule. Even in permanent night shift work, if the worker does not maintain the same schedule on days off as on workdays, he or she will rapidly revert to the natural diurnal orientation (Monk, 1986; Van Loon, 1963). In such circumstances, the circadian system never fully synchronizes to the night schedule. (p. 91)

Paley and Tepas (1994) conducted a study involving firefighters working an 8-hour, rotating (2 weeks per shift) schedule. The results of this study demonstrated that firefighters working this type of schedule will sleep less than normal and will report lower positive mood scores, higher negative mood scores, and higher ratings of sleepiness on the night shift. The results also demonstrated that, over the two-week course of the shift, the firefighters were unable to adapt to changes in their sleep schedule (p. 269).

Research over the past two decades including, Akerstedt & Torsvall, 1981; Rutenfranz et al., 1976; Tepas et al., 1985; Tepas & Carvalhis, 1990; Wiiliamson & Sanders, 1986 (as cited in Paley & Tepas, 1994), indicates that, "workers on the afternoon/evening

shifts sleep longest, workers on the day shift sleep slightly less, and night shift workers sleep least" (Paley & Tepas, 1994, p. 270). In addition to this, Paley and Tepas (1994) also indicate that the partial sleep loss resulting from working shift work should effect individuals with some of the same symptoms that have been seen in studies concerning total sleep loss.

> Partial sleep loss occurs whenever there is a reduction in the usual amounts of sleep obtained in a 24-h period. Johnson and Naitoh (1974) suggested that the factors involved in determining the effects of total sleep loss are equally relevant to partial sleep loss. Therefore, changes in mood state, increased feelings of fatigue and irritability, inability to concentrate, and periods of misperception associated with total sleep loss should also occur from reductions in sleep length or changes in sleep/wakefulness cycles experienced in night work. (p. 270)

Reinberg et al. (1989) conducted a study concerning shift work tolerance and the internal desynchronization of circadian rhythms. It was found that all the participants in the study maintained some diurnal cycles (including temperature), but displayed a desynchronization of heart rhythm, as well as various psychological and behavioral rhythms, while working a rapidly-rotating shift system. Individuals who demonstrated intolerance to shift work complained of drowsiness, fatigue, and lack of attention. "Since an internal desynchronization can be observed in tolerant shift workers having no complaint, it is likely that symptoms of intolerance are

related to the subjects' sensitivity to internal desynchronization rather than to the desynchronization itself" (p. 33).

A report in the U.S. Congress, Office of Technology Assessment (1991) suggests that the age of an individual may also be a factor in his/her ability to adjust to different types of shift work. The report indicates that, as a person ages, the internal clock becomes more difficult to reset, and sleep becomes more fragile and more easily disrupted. These effects usually begin to occur after the age of 45. The report also indicates that surveys of rotating shift workers have found that workers between the age of 45 and 60 years old had more difficulty adjusting to afternoon and night shifts than did younger workers (p. 95).

After reviewing the literature concerning the effects of shift work, Akerstedt (1988) suggests that sleepiness, which results from shift work, may be an underestimated potential hazard in many occupations.

> The results reviewed clearly demonstrate that shift work is associated with increased subjective, behavioral, and psychological sleepiness. The effects are particularly pronounced during the night shift, and may terminate in actual incidents of falling asleep at work. In some occupations this clearly constitutes a hazard that may endanger human lives and have large economic consequences. Furthermore, since night shift sleepiness affects a large majority of individuals engaged in it, the threat is quite real and has probably been underestimated in the past. (p. 30)

Performance

The different types of rotating shift schedules have differential effects on the individuals working them, based upon the type of circadian disruption they cause. As stated earlier, rapidly-rotating work schedules allow the physiological circadian rhythms to remain diurnal, while disrupting the psychological/behavioral rhythms, thus, providing a tendency to disorient the individual. Work schedules which rotate on a weekly basis have social/psychological advantages for the individual, but they also have a direct effect on the physiological rhythms because they disrupt these rhythms with a new routine each week before they have time to adjust. Physiological rhythms can take from seven to several days to adjust to each new routine.

Performance rhythms, however, appear to be less effected on the night shift by rapidly-rotating schedules than by weekly rotating schedules. According to Folkard et al. (1976), rapidly-rotating shift systems affect performance differently according to the memory load involved in the task required of the individual. Low memory load task performance shows a high positive correlation with the physiological temperature rhythm and tends to be poor at night. However, high memory load task performance is negatively

correlated with body temperature and is best at night for rapidly-rotating shift workers.

This finding apparently contrasts with some of the earlier studies concerning the variation in performance during normal waking hours, which found that performance on most tasks tends to improve over the day, while short-term memory tasks performance has a tendency to decrease (p. 21).

> More recent research has indicated that the concept of a single performance rhythm is erroneous and that, like physiological rhythms, performance rhythms differ not only in their normal phase but also in the degree to which they are influenced by exogenous factors (Folkard et al., 1984; Monk et al., 1983). Indeed, there is evidence that memory-loaded, cognitive tasks, which are becoming increasingly common in industry, may be performed particularly well at night provided there is little adjustment of the individual's circadian rhythms (Folkard et al., 1976; Folkard & Monk, 1980). Further, the adjustment of this type of circadian rhythm which peaks at night occurs relatively rapidly (Hughes & Folkard, 1976; Monk et al.,1978). Such adjustment will result in an impairment of night-shift performance and so suggests that, for this type of task, shift systems that minimize adjustment (i.e. rapidly-rotating shift systems) may be preferable. It is thus noteworthy that the only field of study to have found superior performance on the night shift concerned the logging of errors of computer operators (a task with a high memory load) on a rapidly-rotating shift system (Monk & Embrey, 1981). (Folkard et al., 1985, p. 39)

Folkard points out that, from a performance point of view, rapidly-rotating shift systems also have the advantage of minimizing the cumulative sleep debt which can itself impair performance.

Sleep debt can also impede performance dramatically as evidenced by the phenomenon known as night shift paralysis, which prevents the worker from performing his/her job for several minutes. According to Folkard (1985), it appears that, unless the shift worker is engaged in a particularly crucial but relatively simple task, the advantages of permanent shift systems are outweighed by their disadvantages. Rapidly-rotating shift systems minimize cumulative sleep debt and are more advantageous for the performance of memory-loaded, cognitive tasks which are being performed more and more by shift workers (p. 39).

It has been observed, however, that individuals who work rotating work schedules receive lower job performance ratings in some cases. The U.S. Congress, Office of Technology Assessment (1991) reports on the findings of a study concerning the performance ratings of nurses. "Job performance of nurses, as measured by a questionnaire filled out by supervisors, was found to be lower in those on a rotating shift than in those on fixed day, afternoon, or night shifts" (p. 99).

It has also been demonstrated that extended work hours have a negative effect on performance. Rosa and Bonnet (1993) conducted the second of two studies which concerned a change from an 8-hour work schedule to a 12-hour compressed work schedule. After ten

month's adaptation to the new 12-hour shift schedule, workers expressed decrements in performance and alertness which were attributable to the extra 4 hours on the shift. The workers also reported reductions in sleep across the work week which were most significant on the 12-hour night shifts. Rosa and Bonnet indicate that these results are consistent with their earlier findings, and that extra caution should be exercised when scheduling critical activities for workers on extended shifts, especially during extended night shifts, such as the 12-hour shift (p. 1177).

Daniel and Potasova (1989), in a study which compared 8-hour and 12-hour rapidly-rotating shift workers, demonstrated that the temperature rhythm of the 12-hour shift workers goes into rapid decline 4 hours earlier than the temperature rhythm of the 8-hour shift workers. Other results of this study concerned comparisons on performance. Striking changes in performance were noted during the circadian rhythm in psychomotor activities, while the performance curve during more exacting mental activities demonstrated a more uniform pattern. Some of the lower achievements by the 12-hour workers could be attributed to increased fatigue during the longer shift, however, they could possibly be attributed to lower work requirements being assigned to these workers (p. 695).

These and other studies tend to demonstrate some differential effects of shift work schedules, but, regardless of the type of schedules involved, shift work in general has been shown to cause social and domestic disruption for shift workers, which in turn can affect their performance and possibly have costly consequences in industrial settings.

> Work schedules may induce stress by preventing the worker from fuifilling important family roles (Walker, 1985). Social companionships, parenting, and sexual partner roles can all be compromised by work schedules. These effects may be major and can severely affect mood, motivation, and sleep, therefore having indirect effects on performance and safety. Marital problems, excessive domestic load, and community alienation have all been documented as a result of the strain placed on workers by work schedules. (U.S. Congress, Office of Technology Assessment, 1991, p. 93)

Circadian Rhythms and Learning

Instructional design is based on what is known about learning theory, information technology, systematic analysis, and management methods. At the lesson and course levels, strategies are designed so that instruction accommodates the learner. If learning is to take place during instruction, these strategies must include planning which considers both the instruction, and the individual learner. If the learner is not receptive to the instruction for any reason, learning will not take place. Learning is actually a two-way process. Instruction is only effective when the instructional

strategies employed are compatible with the learning style and capabiiities of the learner. The learning style and capabilities of the learner are the individual learner characteristics which are unique to each learner and must be addressed in instructional planning. Learner characteristics include such variables as social background, experiential background, developmental level, motivation, content knowledge, and learning style. Because these characteristics are different for each individual, instructional strategies must be planned to meet each learner's needs.

Chronopsychological research has addressed some other learner attributes as well. As stated earlier, the human short- and long-term memory cycles, and the cycle of alertness all indicate peak periods and low periods at specific times of the day in individuals with normal, diurnal circadian rhythms. It has also been shown that high memory-loaded tasks and tasks involving the synthesis of data are accomplished more effectively at different times of the day for this very reason (Adan, 1993; Folkard, Minors & Waterhouse, 1985; Folkard & Monk, 1980). These, and other, chronopsychological variables operate in rhythmic cycles in all individuals. As Adan (1993) indicates, chronopsychological parameters are not trivial and most psychological research has not even addressed time-of-day as a consideration. She also explains that this could have a been cause for

erroneous experimental results in many cases of past psychological research.

Monk (1989) indicates that the study of psychoiogical circadian rhythms uses the physiological temperature rhythm as a reference for three major reasons:

> The first is simply expedience, body temperature being a well-defined, relatively stable circadian rhythm that can be measured easily by psychologists who lack medical qualifications or radioimmunoassay competence. Second, there is a strong historical tradition, espoused by pioneers such as Kleitman (Kleitman, 1963) and Colquhoun (Colquhoun, 1971), linking psychological rhythms to body temperature rhythms. Third, there are the recent mathematical models of the circadian system (Borbely, 1982; Kronauer et al., 1982; Wever, 1975) which all rely crucially upon the concept of an endogenous circadian oscillator for which the body temperature rhythm is the major indicator. (p. 163)

Monk also indicates that psychological rhythms are not all the same and that, "like the physiological circadian rhythms, psychological rhythms comprise gradual fluctuations over the entire 24 h. Moreover, there are strong intervariable differences" (p. 166). He also states that psychological rhythms are not just specific to each individual. Studies by researchers such as Horne and Ostberg, 1977, and Kerkhof, 1980 (as cited in Monk, 1989), have demonstrated that, even with differences between "morning-type" and "evening-type" individuals, "for the 80 per cent of people who are neither extreme 'morning type' nor extreme 'evening type', one can make

generalizations about psychological circadian rhythms that are valid for the population as a whole" (Monk, 1989, p. 166). Monk goes on to say that the link between subjective alertness and the circadian system makes sense and can be thought of in terms of psychological rhythms acting as an interface between the physiological circadian processes and the sleeping and waking behaviors that those processes influence (p. 166).

Monk's own research in forced desynchronization studies in 1987 (as cited in Monk, 1989) determined the relationship between the temperature rhythm and the subjective alertness rhythm. Monk has determined that, when the sleep-wake cycle is driven at a point which is beyond the range of the endogenous circadian oscillator controlling the temperature rhythm, the oscillator assumes a period length which is close to the free-running 25-hour cycle. This causes two periodicities to be present in the data, that of the sleep-wake cycle, and that of the temperature rhythm. Examination of the data has demonstrated that both periodicities influence the subjective alertness rhythm. A parallelism between the alertness rhythm and the temperature rhythm exist at the temperature rhythm oscillator period, and the maximal subjective alertness was found, on the sleep-wake cycle, to occur from 8 to 10 hours after waking. These data coincide with the early afternoon peak in alertness which is

usually found. Monk goes on to say that the relationship between subjective alertness and body temperature can be explained by postulating control by both the temperature rhythm oscillator and the sleep-wake mechanism, with the sleep-wake mechanism tending to have more dominant control under normal, diurnal sleep-wake patterns (Monk, 1989, p. 167).

In addition to the subjective measures of alertness, there are also many circadian rhythms which lend themselves to objective measures of performance efficiency. Some performance rhythms run parallel to the circadian temperature rhythm and can be measured in this manner.

> Colquhoun (Colquhoun, 1971) studied vigilance tasks (detection of an infrequent signal), simple addition tasks (adding up 6 two-digit numbers), and other simple reaction-type tasks, finding them to parallel (in measures of speed) the circadian temperature rhythm, even during the process of adjustment to a change in routine. This observation confirmed earlier studies by Kleitman (Kleitman, 1963), which used fewer subjects, but still a rather "simple repetitive" collection of tasks, such as card dealing and reaction time. Later, a collection of serial search tasks (Monk, 1979), in which subjects scan through material for particular targets (e.g. every occurrence of the letter "e" in a magazine article) again revealed a very good parallelism (in speed) with the body temperature rhythm....
> (Monk, 1989, p. 168)

Monk's research also determined that performance speed parallels the temperature rhythm. However, when performance accuracy was measured, performance was found to decline over the

day, reaching the lowest point of accuracy at the same time of the day as the peak in performance speed. Thus, while performance speed is increasing over the day, performance accuracy is declining (Monk, 1989, p.169).

Colquhoun also conducted a study concerning speed in arithmetic addition. This study concluded that, as the task became more repetitive and simple, the time-of-day function in performance speed became more like that of the temperature rhythm. Therefore, time-of-day functions may change with practice.

For Monk (1989), these findings suggests that it may be wrong to speak of performance as improving over the day, or to think of time-of-day factors as representing changes in the brain's capacity to process information. Monk believes that we should consider changes in performance as being mediated by changes in strategy over the day. Individuals probably approach information processing tasks differently at one time of the day, and at one level of practice, as compared to another. Measures may indicate better or worse performance depending upon what type of measure we take (p. 170).

Monk also suggests that research on short-term memory, which indicates a decline over the day, may also be a result of changes in information processing strategy, rather than changes in the brain's capacity to process information. "In several studies (Folkard, 1979;

Folkard & Monk, 1979; Folkard & Monk, 1985) a manipulation that inhibited subvocalization was also found to eliminate the time-of-day effect, suggesting that time-of-day differences may also result from differences in subvocalization strategy" (p. 170).

According to the U.S. Congress, Office of Technology Assessment (1991), in a diurnal condition, certain psychological rhythms are evident, though they may be inconsistent.

> It was found that, if speed of identification was assessed, the usual relationship with temperature held--that is, subjects became faster over the course of the day. However, if accuracy of response became the benchmark, peak performance occurred in the morning (Craig & Condon, 1985; Monk & Leng, 1986). Short-term and long-term memory also appear to peak at different times during the 24-hour cycle (Folkard & Monk, 1980). Motivation can influence performance, too. It has been shown that when an incentive is offered, such as a significant sum of money, circadian decrements in performance may be overcome to some extent (Colquhoun, 1981; Horne & Pettitt, 1985). The latter study (Horne & Pettitt, 1985) indicated, however, that sleep deprivation and circadian rhythms can overcome even the strongest incentive influencing performance. Further complicating the picture is the observation that individuals are not always accurate judges of their own mood, alertness, or ability. (p. 47)

Englund (1979) conducted a study of the diurnal function of reading rate, comprehension and efficiency. The results of this study indicate that the plotted means for these variables displayed distinct diurnal patterns. Analysis of the data revealed that comprehension was superior in the afternoon and early morning when compared to

scores at mid-morning and late at night. Performance speed indicated a morning rise and afternoon fall. Oral temperature of the subjects peaked at 15:27, with no differences being found between males and females. Overall efficiency displayed no significant differences, indicating a trade-off between speed and accuracy over the day, which acts to maintain performance efficiency. "These findings confirm Folkard's observations (Brit. J. Psychol., 1975), while performance is task dependent, speed and accuracy measures may represent different diurnal components of performance with correspondingly different relationships to arousal level" (Englund, 1979, p. 96).

Taking all of this into consideration, Adan (1993) conducted a literature review in order to classify the most commonly used psychological tests, and to differentiate these tests on the basis of variations obtained according to time-of-day factors. She indicates that the incipient state of chronopsychology stems from two basic facts. First, there is a great heterogeneity in the results obtained which is a consequence of the diversity of methods used, the samples of subjects and the situations in which the various experiments were conducted. Second, most psychological investigations ignore the time-of-day factor as both a procedural variable and as a means of control in experiments. Adan further explains:

> Daily fluctuation in behavioral parameters cannot be considered trivial: the total variation detected is of the order of10 %, and "over the normal waking day (0800 to 0000) the circadian variation in performance efficiency can be equivalent in magnitude to the effect of iimiting sleep to 3 hours or ingesting the legal driving iimit of alcohol" (Monk et al., 1978, p. 166). (p. 146)

Adan also indicates that other rhythms with different periodicities (circamensual rhythms = greater than 24 hours, and ultradian rhythms = less than 24 hours) may mask the results of studies concerning circadian rhythms and, therefore, should be controlled.

Nevertheless, the classification proposed by Adan (1993) enables us to differentiate, from a chronopsychological viewpoint, the most commonly used tests based upon both the required skill of each test, and the empirical criterion of the resultant circadian function. The advantage of Adan's classification over traditional classifications is that coherence is imposed on the heterogeneity of the existing results for both subjective and objective tests.

The subjective tests yield data concerning the subjects' own assessment of his/her state during the test. The two principal types of tests include self-assessment inventories, and analogico-visual scales. Patterns of alertness, as measured on the analogico-visual scales, shows a peak alertness between 11:00 and 14:00, and somnolence demonstrates an opposed two-phase pattern. The

pattern of drowsiness indicates high scores at 07:00-09:00 and at 21:00-23:00.

Objective tests consist of tasks which are generally normalized, and are designed to make it difficult for subjects cheat. Subjects are presented with indicators from which to chose as a criterion of performance, and these differ as to whether the circadian function being tested is quantitative or qualitative. Adan's classification has completely changed the traditional dichotomization of vigilance and cognitive tasks by subclassifying them into the categories of simple and complex tasks. Simple tasks differ as to their motor component. Tasks with a weak motor component include vigilance tasks and signal detection and/or discrimination tasks. Signal detection and discrimination tasks demonstrate a 4-hour advance of the optimum time with respect to that of vigilance tasks. Of the high motor component tasks, only those requiring manual skill demonstrate circadian rhythmicity, and peak performance on these tasks occurs between 12:00 and 14:00.

As with the majority of earlier studies, Adan subdivides complex tasks into memory tasks and tasks of greater cognitive complexity. Memory tasks demonstrate circadian variations which are most pronounced in optimum time, and this is different in each case: immediate memory 08:00-10:00, working memory 12:00-14:00, and

long-term memory 18:00-20:00. Very little data exist concerning tasks of greater cognitive complexity, and results are inconclusive (Adan, 1993, p. 154).

This seems to indicate that, for whatever reason, a rhythmicity exists. Folkard and Monk (1980) indicate that short-term memory generally peaks in the morning, and that long-term memory generally peaks in the afternoon, thus, providing implications for the timing of instruction according to the type of instructional objectives involved.

Regardless of whether a direct link can be made between certain variables and a circadian pacemaker, the aforementioned research does demonstrate that temporal ordering of these variables does exists and can be observed and predicted.

> Consider the following reported data: the frequency of heart attacks peaks between 6 a.m. and noon (Muller et al., 1985; Rocco et al., 1987); Asthma attacks are most prevalent at night (McFadden, 1988); human babies are born predominantly in the early morning hours (Glattre & Bjerkedal, 1983; Kaiser & Halberg, 1962). While these patterns do not necessarily indicate that the events are driven by the circadian pacemaker, they do suggest temporal order in the functioning of the human body. (U.S. Congress, Office of Technology Assessment, 1991, p.41)

One study was conducted in order to determine the effect of the timing of learning relative to the timing of sleep on memory retention. Benson and Feinberg (1975) conducted a study concerning the effects of sleep on memory by comparing the memory retention

of two groups. The two groups were divided in order to examine retention of initial learning in the morning versus retention of initial learning at night, at both 8 hours and 24 hours after the initial learning was accomplished. The results indicated that retention was superior 8 hours after learning for subjects who learned at night, as compared to those who learned in the morning. Retention for subjects who learned at night was equal after 24 hours to that observed after 8 hours. A rather surprising finding in this study was that retention scores for subjects who learned in the morning were superior after 24 hours to those observed at 8 hours after initial learning (p. 192).

A recent study (Shadmehr & Holcomb, 1997) indicates that it takes about six hours for the memory of a new skill to move into long-term memory storage. This study also indicates that practice of a similar skill just after learning the new skill can interfere with the long-term memory storage of the new skill, but that practice of a non-similar skill may not interfere. These findings may have implications for the surprising results obtained by Benson and Feinberg.

Summary

This chapter has described human biological and psychological circadian rhythms and how they are controlled by both endogenous and exogenous factors. This chapter also described the detrimental effects of circadian dysrhythmia, which are caused by jet lag or rotating shift work, and the effects of circadian rhythms on learning. The following chapter describes the methods and procedures used in this study to collect and analyze the data, in order to address the hypotheses presented in Chapter 1.

CHAPTER 3
METHODOLOGY

Participants

Thirty-seven participants (N = 37) were self-selected from the Jacksonville, Florida, Air Route Traffic Control Center (ARTCC). Although this sample is representative of the population of interest, this number is less than the desired number of participants for this type of study and may slightly limit the generalization of the findings. Participants were recruited on a voluntary basis, so that two groups (18 rapidly-rotating shift workers, and 19 day/evening shift workers) were obtained. The population for this study consisted of six female controllers (three in each group) and thirty-one male controllers, all 45 years of age or younger. The majority of the participants were in their late 20s or early 30s.

Instruments

The NovaScan computer-based performance test was the instrument used to gather data for this study. This test was used to measure five variables: (a) Dial monitoring reaction time during the spatial-visualization task (attention allocation), (b) dial monitoring reaction time during the tracking task (attention allocation),

(c) reaction time for transition from the tracking task to the spatial-visualization task (flexibility in switching resources), (d) non-transition reaction to object orientation (spatial visualization), and (e) tracking error during the tracking task (straight mind/motor coordination).

The NovaScan instrument randomly presents two computer-based tasks for the participant to perform several times during each session. Task 1 (spatial visualization) is a cognitive task in which the participant must orient an airplane by selecting the wing which has the circle above it like the one below the airplane. The circles are either open or solid, and one wing has one of these above it, while the other wing has the other. The participant must respond either "left" or "right" to select the correct wing by pressing buttons on a special keyboard. The reaction times for the participant's responses are recorded in milliseconds.

Task 2 (tracking) is a psychomotor task in which the participant must use a joy stick to move the computer's cursor left and right to try to keep it below a horizontally-moving object. The tracking error at this task is recorded, as the mean number of pixels that the cursor was off target and outside the range of the area directly below the moving object during the session.

While the participant is completing these two randomly-presented tasks during a NovaScan session, he/she must continuously monitor a dial in the upper right corner of the screen to determine when the pointer on the dial moves into a solid area. When this occurs, the participant must respond by pressing another button on the special keyboard. The participant's responses are recorded in milliseconds and represent the participant's attention allocation rating during each of the two tasks.

The reliability measures for the NovaScan variables, obtained from parametric studies, have been rated via intra-class correlation as follows: Rotated object (.95), transition to object visualization task (.94), and tracking error (.91). These measures are calculated by subtracting the within variance from the between variance, and dividing by the between variance (O'Donnell, 1992). The attention allocation variable has only been used in the past for the purpose of measuring an individual's current attention allocation against his/her own baseline rating. It has never before been used to compare the ratings of groups of individuals.

Materials/Apparatus

NovaScan requires a PC with 286 or faster processor, one MB of RAM, a VGA graphic adapter (black and white or color), a hard-drive disk (if desired), and DOS 3.3 or higher operating system. A special

keyboard is provided for responding. These minimum requirements were met using two 386 MHz DOS computers. Each participant was provided with a single 3.5 in floppy disk, which contained the NovaScan software, so that all NovaScan sessions could be recorded separately for each individual.

Design

A causal-comparative design was used for this study since the predictor variable (work schedule) is already differentiated between the two study groups, and because the cause (circadian dysrhythmia) is already suspected and the effect (attention allocation) is under investigation. Self-selected participants were categorized into two groups. One group of participants was represented by individuals who work day and evening two-shift schedules, and the other group only included individuals who work a variety of rapidly-rotating three-shift schedules which include night shifts.

The variables which were controlled include the following considerations: (a) The rotating schedules included at least one midnight shift and one day shift each week prior to the NovaScan sessions, so that the daily routines of the individuals who worked them were acutely shifted, (b) all of the participants were no more than 45 years of age, so that the circadian effects of aging were not a factor, (c) all testing periods on the NovaScan took place during the

day shift hours (8:00 am to 4:00 pm) for each participant, in order to determine each individual's attention allocation during the hours that training normally occurs, and (d) all participants indicated that they were not taking any medications, such as cold remedies or prescription drugs, which may have an effect on alertness or attention allocation ratings. Controllers who take such medications are not authorized to work operational positions in any event, so a simple acknowledgement to this requirement was all that was required.

Procedure

Each specialist completed no more than 6 sessions per day on NovaScan, on no less than 7 separate days, between the hours of 8:00 am and 4:00 pm, untll 25 sessions were completed. Parametric studies for NovaScan indicate that a stable baseline measure for any individual should be completed by the 20th session, and that massed practice should be avoided by allowing at least 7 separate days for practice.

Since the rotating shift workers only work two or three day shifts each week, the investigator obtained a six-week temporary duty assignment to the Jacksonville ARTCC in order to have enough time for the purpose of participant recruitment and data collection. The day and evening shift participants also kept a similar schedule

for their sessions on NovaScan by taking their sessions on two or three days of each week.

The procedure described above was necessary because the controllers could not be scheduled to take their sessions at predesignated times. The controllers were all volunteer participants, and they could only be requested to report for their sessions during their break times if/when they were willing to do so. Because of this slight design problem, certain trends may have been missed in the analysis which could have provided more information.

Null Hypotheses

Data were collected and analyzed to address the following:

1. Air traffic controllers who work rapidly-rotating work schedules, will show no significant difference from controllers who work day-shift and/or evening-shift schedules on their NovaScan mean baseline rating of attention allocation for dial monitoring during the spatial visualization task (Task #1).
2. Air traffic controllers who work rapidly-rotating work schedules will show no significant difference from controllers who work day-shift and/or evening-shift schedules on their NovaScan mean baseline rating of attention allocation for dial monitoring during the tracking task (Task #2).

3. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of reaction time on dial monitoring during the spatial visualization task (Task #1).

4. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of reaction time on dial monitoring during the tracking task (Task #2).

5. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of reaction time for the transition from Task #2 to Task #1 (which indicates response flexibility in switching resources).

6. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of

controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of reaction time on Task #1 non-transition object orientation (which indicates spatial visualization).

7. Air traffic controllers who work rapidly-rotating work schedules will indicate a mean learning curve (slope and its residuals) which is not significantly different from the mean learning curve of controllers who work day-shift and/or evening-shift schedules for their NovaScan repeated measures of tracking error on Task #2 (which indicates mind/motor coordination).

Variables

The following criterian variables were measured and analyzed:

1. Attention allocation during Task 1 (spatial visualization).
2. Attention allocation during Task 2 (tracking).
3. Reaction time to transition from Task 2 to Task 1 (response flexibility in switching resources),
4. Non-transition reaction time to Task 1 (spatial visualization).
5. Tracking error during Task 2 (tracking).

Data Analysis

In order to answer the hypotheses, the data were analyzed so that the two groups of participants could be compared on two types of variables: attention allocation, and learning. This was accomplished in the following manner:

1. The two baseline measures of attention allocation for each individual were calculated as the average reaction time on dial monitoring during tasks 1 and 2 from the last 3 sessions taken on NovaScan. Once all the participants had completed their 25th session on NovaScan, a t-Test for independent samples was completed for each measure with p=0.05 defined as statistically significant. The results of these t-Tests were used to compare the two groups of participants on each of these two measures and to address hypotheses 1 and 2.

2. The learning curves for each individual were determined for the five NovaScan variables: (a) Attention allocation during the spatial visualization task, (b) attention allocation during the tracking task, (c) response flexibility in switching resources, (d) non-transition reaction to spatial visualization, and (e) tracking error during tracking. The mean learning curve for each variable was determined for each group to be used to compare the two groups of participants and to address hypotheses 3 through 7.

A Two-Way General Linear Model, Repeated-Measures Analysis, which included three statistical test (Group Main Effect, Time Main Effect, and Group/Time Interaction) was used to analyze the data for the five variables' mean learning curve slopes and their residuals with p=0.05 defined as statistically significant, in order to compare

the two groups' progress over the sessions. Wherever a Group/Time Interaction was found to be statistically significant, the Group Main Effect and Group Time Effect were not reported (per rule). Also, for each test that was found to be statistically significant, eta squared (η^2) was calculated in order to determine whether the significant difference was slightly (η^2=0.01), moderateiy (η^2=0.06), or highly (η^2=0.14) meaningful for the size of the sample used in this study. According to Cohen (1988), eta squared is the proportion of total variance in the outcome that is accounted for by the between group variance. In short, eta squared determines if the significant difference between the groups is meaningful, and a moderate eta squared result (η^2=0.06), or higher, would meet this standard. The learning curves for the two groups were superimposed and displayed together for visual comparison on each variable, and each group's mean learning curves were displayed individually with their error bands (standard deviations).

Only the last three seconds (time period two) of each trial for variables 2 (attention allocation during tracking) and 5 (tracking error during tracking) were used in the calculation for these tasks, in order to control for the variable state of the tracking task at each of its initiations. For this same reason, variable 3 (response flexibility

in switching resources) was always reported as a transition from the tracking task to the spatial visualization task, and not the other way around.

Summary

Chapter 3 has presented the methodology used in the data collection process, the participants who volunteered for the study, and the procedures used to collect the data. This chapter also stated the hypotheses and variables addressed in the investigation and the data analysis procedures used to determine the results. The following chapter presents the research findings which resulted from these methods and procedures, and Chapter 5 concludes with a discussion of the results, the theoretical and practical implications of this research, and recommendations for future research.

CHAPTER 4
RESEARCH FINDINGS

Results

Hypothesis 1

A statistically-significant difference was found between the two groups' attention allocation baseline measure for dial monitoring during Task 1 (spatial visualization). Group 1 (Rapidly-Rotating Shift Workers) demonstrated a better attention allocation rating (a faster reaction time for dial monitoring) during Task 1 (spatial visualization) than Group 2 (Day/Evening Shift Workers) demonstrated. The null hypothesis was rejected.

Hypothesis 2

A statistically-significant difference was found between the two groups' attention allocation baseline measure for dial monitoring during Task 2 (tracking). Group 1 (Rapidly-Rotating Shift Workers) demonstrated a better attention allocation (a faster reaction time for dial monitoring) during Task 2 (tracking) than Group 2 (Day/Evening Shift Workers) demonstrated. The null hypothesis was rejected.

Hypothesis 3

A statistically-significant Group/Time Interaction with a small effect size was found between the two groups' mean learning curves for Variable 1: dial monitoring (attention allocation) during Task 1 (spatial visualization). Group 1 (Rapidly-Rotating Shift Workers) demonstrated a decreasing learning curve with an improving reaction time over the sessions, while Group 2 (Day/Evening Shift Workers) demonstrated a fairly flat learning curve. Both groups demonstrated stabilization around their mean baseline measures, with no Group/Time Interaction between the groups' residuals. The null hypothesis was rejected.

Hypothesis 4

No statistically-significant Group Main Effect, Time Main Effect, or Group/Time Interaction was found between the two groups' learning curve slopes for Variable 2: dial monitoring (attention allocation) during Task 2 (tracking). The learning curve slopes for the two groups appear statistically the same (fairly flat) and did not improve to a statistically-significant degree over time. Both groups demonstrated a stabilization around their mean baseline measure, however, the groups' residuals demonstrated a statistically-significant Group/Time Interaction with a moderate effect size, indicating a difference in the groups' residuals when compared over

the sessions. The standard deviations around the means of the slopes were not the same for the groups when compared over time and the groups did not stabilize around their means at the same rate. The null hypothesis was rejected.

Hypothesis 5

No statistically-significant Group Main Effect or Group/Time Interaction was found between the two groups' learning curves for Variable 3: reaction time during the transition from Task 2 to Task 1 (response flexibility in switching resources), indicating that the groups' mean learning curves appear statistically equal. There was, however, a statistically-significant Time Main Effect with a large effect size, indicating that both groups' learning curves depict improved reaction times over the sessions. No error-band effects were found to be statistically significant, indicating no statistically-significant change in them over time, and no Group/Time Interaction between the error bands. The null hypothesis was not rejected.

Hypothesis 6

No statistically-significant Group Main Effect or Group/Time Interaction was found between the two groups' learning curves for Variable 4: reaction time during Task 1 (spatial visualization), indicating that the groups' mean learning curves appear statistically equal. There was, however, a statistically-significant Time Main

Effect with a large effect size, indicating that both groups' learning curves depict improved reaction times over time. No error-band effects were found to be statistically significant, indicating no statistically-significant change in them over time, and no Group/Time interaction between the groups' error bands. The null hypothesis was not rejected.

Hypothesis 7

No statistically-significant Group Main Effect or Group/Time interaction was found between the two groups' learning curves for Variable 5: tracking error during Task 2 (tracking), indicating that the groups' mean learning curves appear statistically equal. There was, however, a statistically-significant Time Main Effect with a moderate effect size, indicating that both groups' learning curves depict improved tracking errors over time. No error-band effects were found to be statistically significant, indicating no statistically-significant change in them over time, and no Group/Time interaction between the error bands. The null hypothesis was not rejected.

Attention Allocation

Table 1 displays the results of the two comparisons of attention allocation baseline for the two groups, based on the two t-Tests. The first group comparison (attention allocation during the spatial visualization task) indicates that the mean baseline measure for

Table 1. Summary of t-Test Results for Group Mean Attention Allocation Comparisons in Milliseconds of Reaction Time

	Group 1			Group 2		
Variable	n	M	SD	n	M	SD
Task 1	18	616.57	107.15	19	778.64	140.91
			(t=3.92, p=0.002, rpb=0.31)			
Task 2	18	1548.42	55.27	19	1659.16	103.61
			(t=4.02, p=0.0001, rpb=0.32)			

*p<0.05

Group 1 (Rapidly-Rotating Shift Workers) is 616.57 milliseconds of reaction time, while the mean measure for Group 2 (Day/Evening Shift Workers) is 778.64 milliseconds of reaction time. As determined by the t-Test, this difference is statistically significant [t(35)=3.92, p=0.002, rbp=0.31].

The second group comparison (attention allocation during the tracking task) indicates that the mean baseline measure for Group 1 is 1548.42 milliseconds of reaction time, while the mean measure for Group 2 is 1659.16 milliseconds of reaction time. As determined by

Table 2. Summary of Learning Curve Analyses

VRBL	Fig.	Test	F Value	p Value	Eta Squared
1	1	Slope/GTI	2.96	0.02	0.03
	6/7	Resdl/GME	0.37	0.55	
	6/7	Resdl/TME	12.3	0.0001	0.19
	6/7	Resdl/GTI	1.7	0.11	
2	2	Slope/GME	0.01	0.94	
	2	Slope/TME	2.29	0.13	
	2	Slope/GTI	1.01	0.34	
	8/9	Resdl/GTI	3.96	0.05	0.09
3	3	Slope/GME	0.78	0.38	
	3	Slope/TME	43.35	0.0001	0.17
	3	Slope/GTI	0.9	0.47	
	10/11	Resdl/GME	1.37	0.25	
	10/11	Resdl/TME	0.97	0.43	
	10/11	Resdl/GTI	0.88	0.49	
4	4	Slope/GME	0.51	0.48	
	4	Slope/TME	72.3	0.0001	0.29
	4	Slope/GTI	2.05	0.09	
	12/13	Resdl/GME	2.03	0.16	
	12/13	Resdl/TME	1.24	0.30	
	12/13	Resdl/GTI	0.63	0.66	
5	5	Slope/GME	0.56	0.46	
	5	Slope/TME	12.31	0.0001	0.10
	5	Slope/GTI	0.50	0.85	
	14/15	Resdl/GME	0.38	0.54	
	14/15	Resdl/TME	1.55	0.15	
	14/15	Resdl/GTI	0.64	0.73	

Abbreviations used in Table 2: Resdl=Residual; GME=Group Main Effect; TME=Time Main Effect; GTI=Group/Time Interaction

*$p<0.05$

the t-Test, this difference is also statistically significant [t(35)=4.02, p=0.0001, rpb=0.32].

Learning Curve Comparison

Table 2 describes a summary of results for the learning curve analyses and how they relate to the learning curves displayed in Figures 1 through 15. Figures 1 through 5 display the mean learning curves for Groups 1 and 2 (superimposed) for each of the five variables, while Figures 6 through 15 display each group's independent learning curve for each variable with its error band (standard deviation).

As indicated in Table 2, there is a statistically-significant Group/Time Interaction between the groups' learning curves for Variable 1, dial monitoring reaction time during Task 1 (spatial visualization). The eta squared value for this interaction is 0.03, which indicates a slight to moderate effect size. This interaction implies that the slopes of the two groups' learning curves appear to be different. Group 1 displays a decreasing slope, while Group 2 displays a fairly flat slope with little improvement over time. The apparent difference between the two slopes can be seen in Figure 1, and the statistically-significant difference which was found in the baselines by the t-Test for the final three sessions is obvious.

There is no Group/Time Interaction for the groups' residuals on Variable 1. The Group Main Effect test (Table 2) for the residuals indicates that the error bands are statistically the same size for both groups (Figures 6 and 7), while the Time Main Effect test demonstrates a statistically-significant effect, indicating that the error bands for both groups become smaller over the sessions. The eta squared for the Time Main Effect is 0.19, indicating a large effect size. It is apparent that the error bands become more stable around the means over the sessions for both groups, but Group 1 appears to stabilize slightly more than does Group 2.

The Group/Time Interaction comparison for Variable 2, dial monitoring reaction time during Task 2 (tracking), produced a statistically non-significant result, meaning that the slopes appear to be statistically the same when compared over time. The slope comparison for Groups 1 and 2 (Table 2) indicates that the slopes statistically appear to be the same, with no statistically-significant Group Main Effect (Figure 2). There is also no statistically-significant Time Main Effect, indicating that the slopes did not increase or decrease to a statistically-significant degree over the sessions. The statistically-significant difference which was found between the two groups' baselines by the t-Test for this variable is apparent, but not as obvious as with Variable 1.

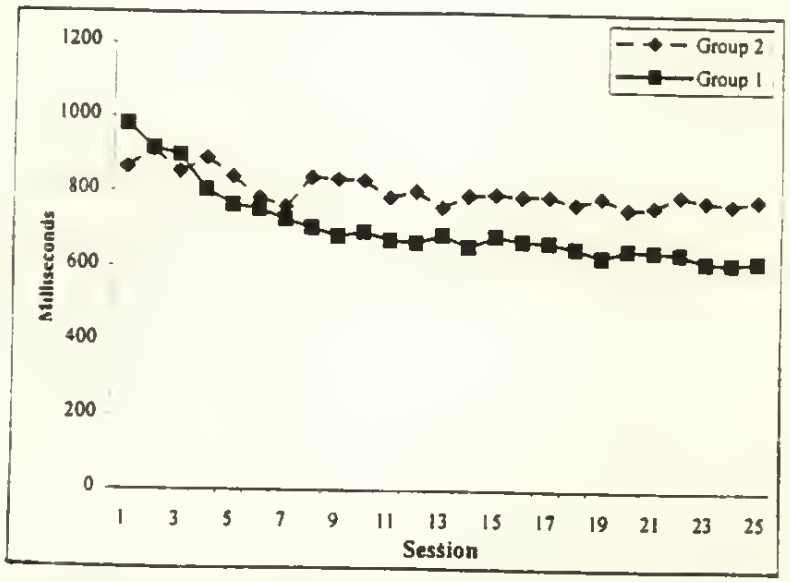

Figure 1. Mean learning curves for dial monitoring reaction time during Task 1 (Spatial Visualization).

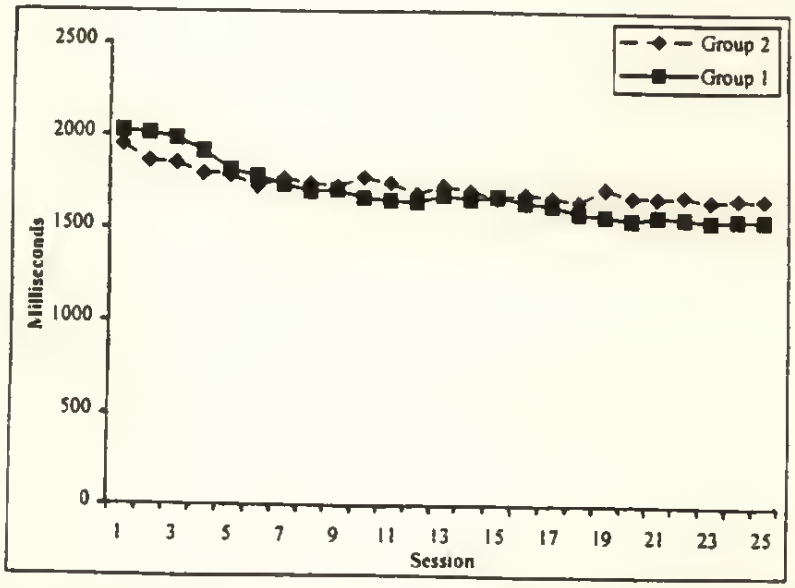

Figure 2. Mean learning curves for dial monitoring reaction time during Task 2 (Tracking).

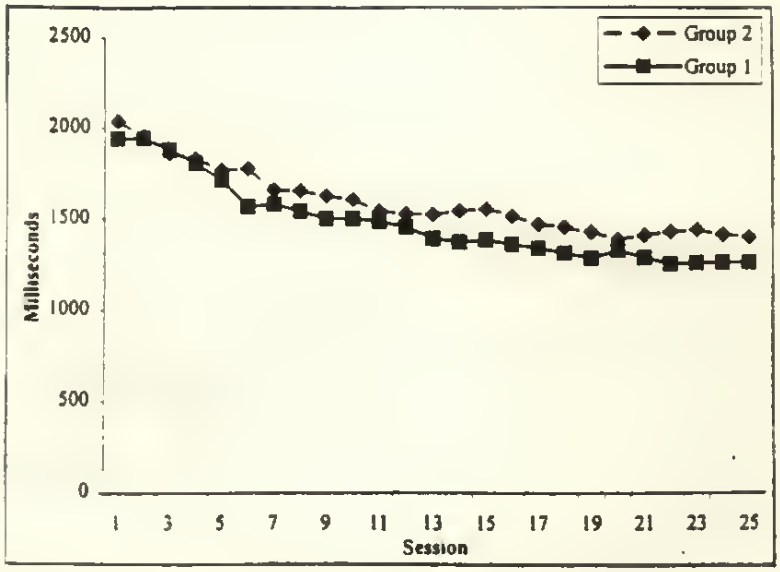

Figure 3. Mean learning curves for reaction time to transition from Task 2 (Tracking) to Task 1 (Spatial Visualization).

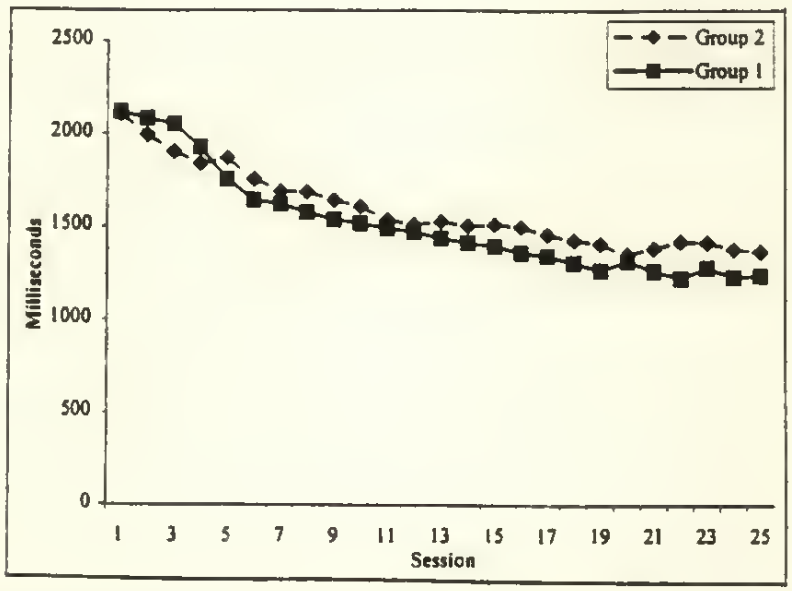

Figure 4. Mean learning curves for reaction time to Task 1 (Spatial Visualization).

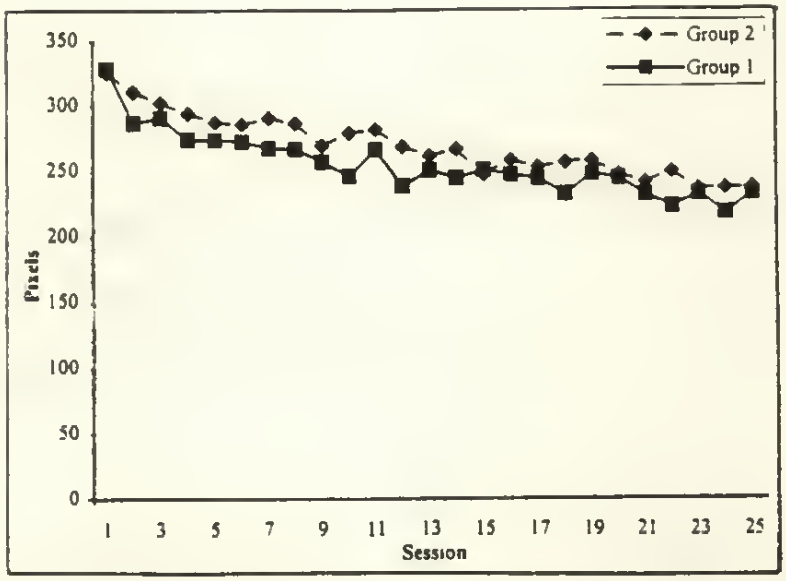

Figure 5. Mean learning curves for tracking error during Task 2 (Tracking).

The residual tests (Table 2) for Variable 2 demonstrates a statistically-significant Group/Time Interaction with a moderate effect size (η=0.09) for the residuals (Figures 8 and 9). This indicates that the size of the error bands decrease at statistically different rates over time for the two groups.

The statistical analyses (Table 2) for Variables 3 (reaction time during transition from Task 2 to Task 1), 4 (reaction time during Task 1), and 5 (tracking error) all had similar results. There was no Group/Time Interaction between the groups on any of these three variables, indicating that the slopes of the groups appear statistically the same over the sessions in each case. As Figures 3, 4, and 5

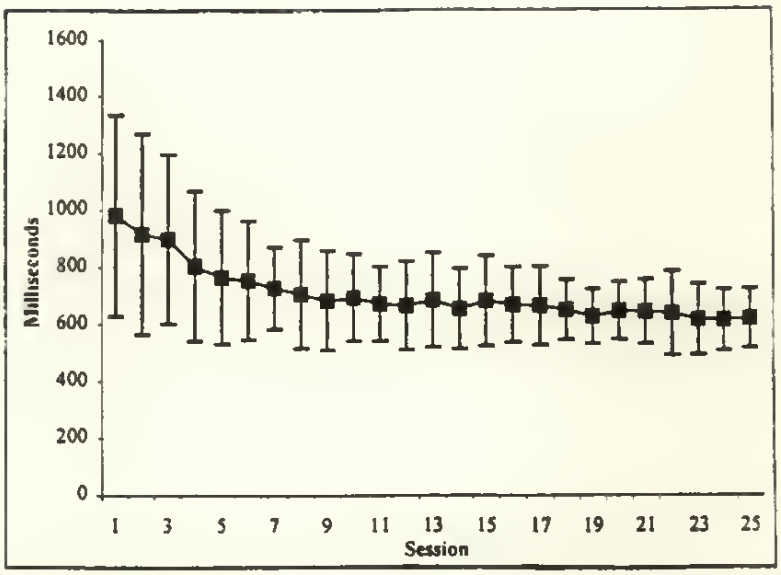

Figure 6. Group 1 mean learning curve with error band (standard deviation) for dial monitoring reaction time during Task 1 (Spatial Visualization).

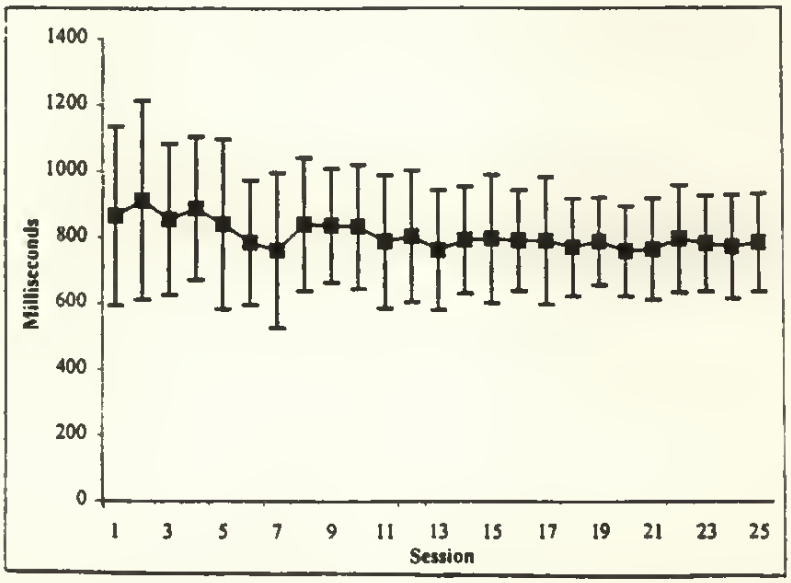

Figure 7. Group 2 mean learning curve with error band (standard deviation) for dial monitoring reaction time during Task 1 (Spatial Visualization).

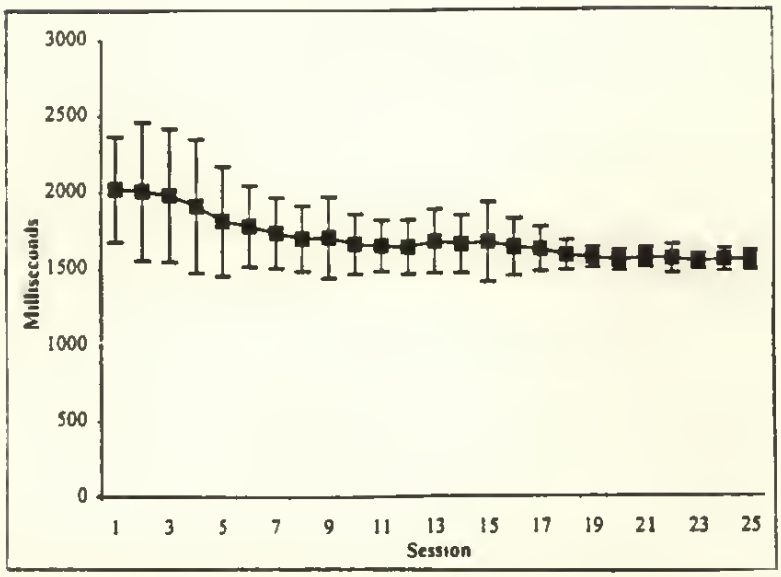

Figure 8. Group 1 mean learning curve with error band (standard deviation) for dial monitoring reaction time during Task 2 (Tracking).

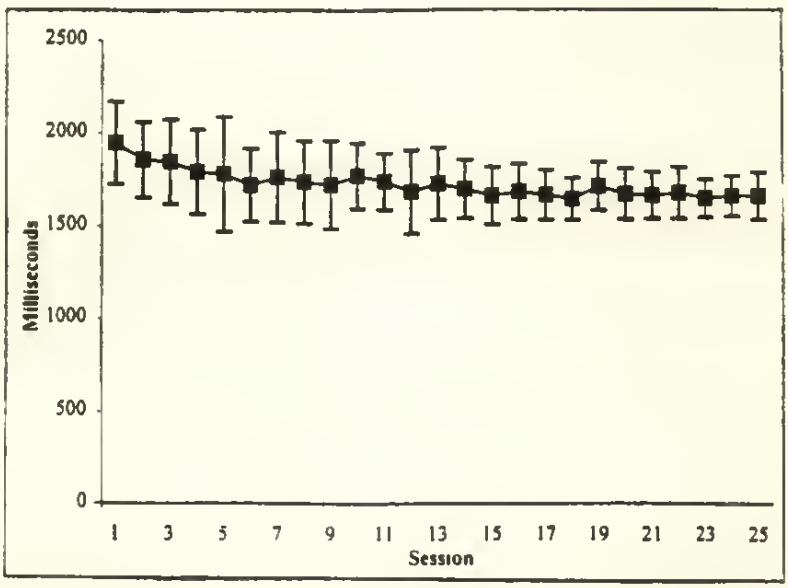

Figure 9. Group 2 mean learning curve with error band (standard deviation) for dial monitoring reaction time during Task 2 (Tracking).

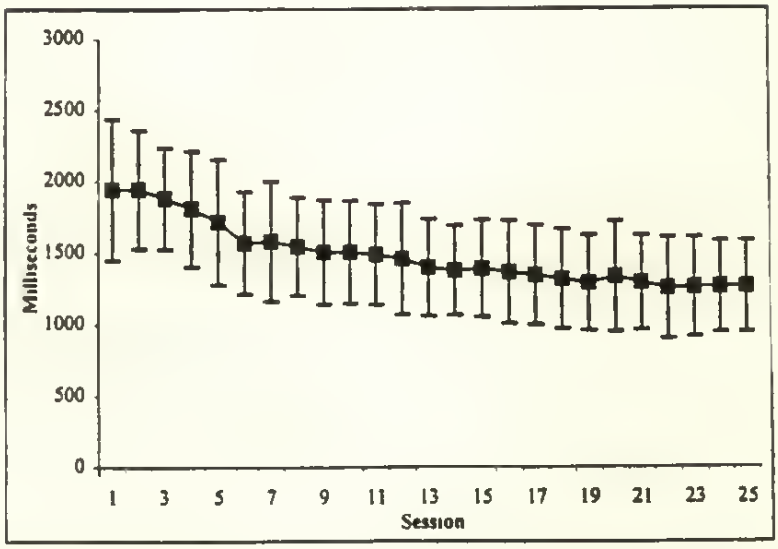

Figure 10. Group 1 mean learning curve with error band (standard deviation) for reaction time to the transition from Task 2 (Tracking) to Task 1 (Spatial Visualization).

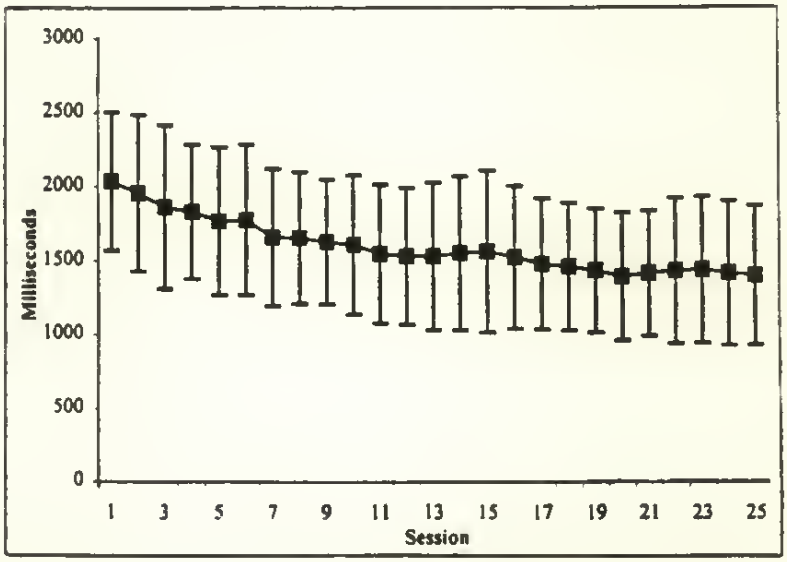

Figure 11. Group 2 mean learning curve with error band (standard deviation) for reaction time to the transition from Task 2 (Tracking) to Task 1 (Spatial Visualization).

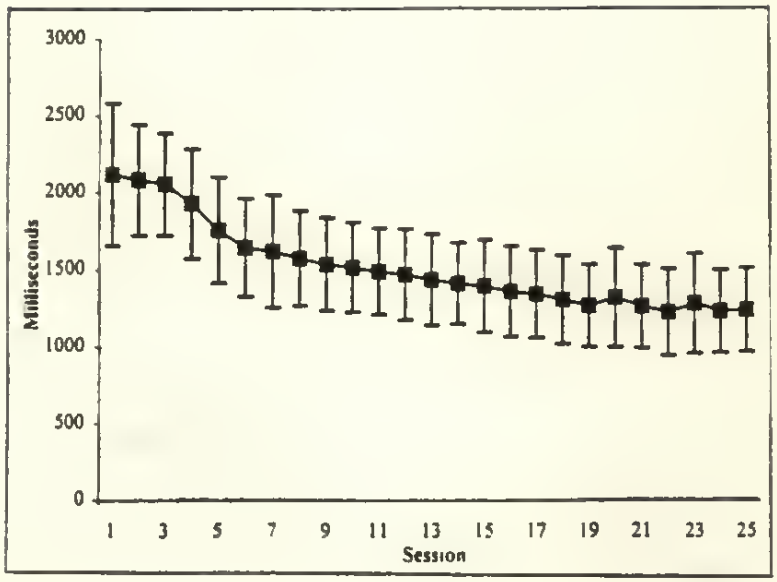

Figure 12. Group 1 mean learning curve with error band (standard deviation) for reaction time to Task 1 (Spatial Visualization).

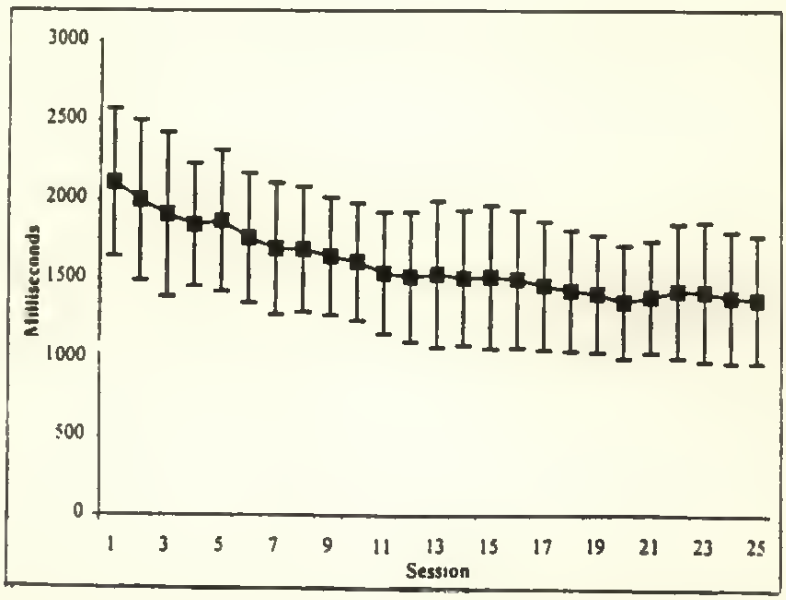

Figure 13. Group 2 mean learning curve with error band (standard deviation for reaction time to Task 1 (Spatial Visualization).

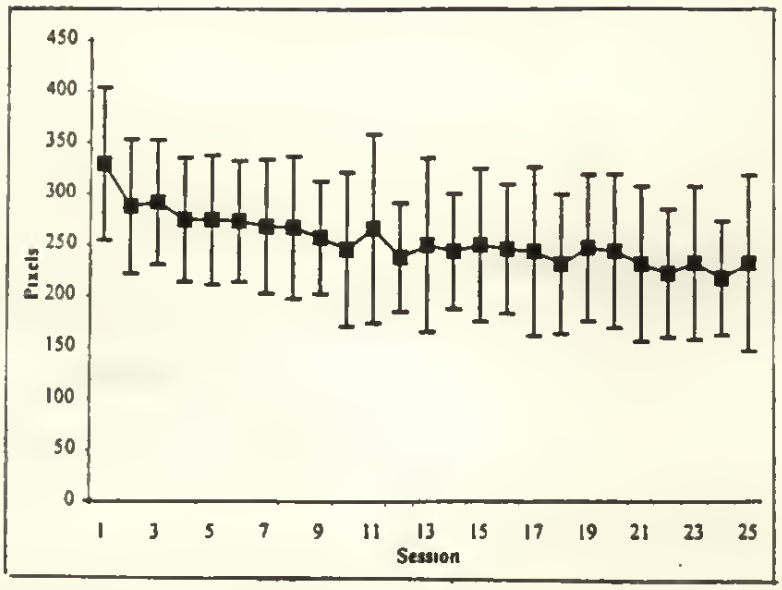

Figure 14. Group 1 mean learning curve with error band (standard deviation) for tracking error during Task 2 (Tracking).

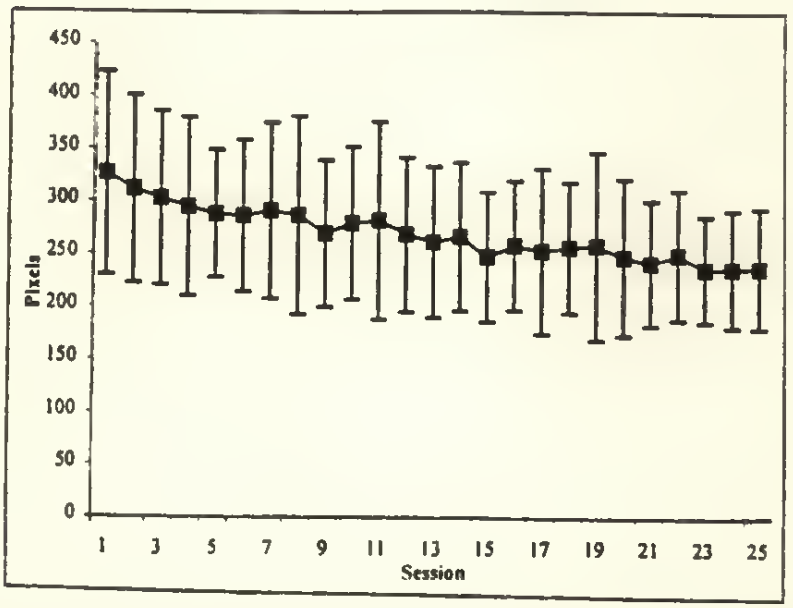

Figure 15. Group 2 mean learning curve with error band (standard deviation) for tracking error during Task 2 (Tracking).

illustrate, there are no Group Main Effects, indicating that the slopes for both groups look similar in each case. There is, however a statistically-significant Time Main Effect for all three variables, meaning that both groups improved their reaction times over the sessions on each variable. The eta squared value for this effect on Variables 3 and 4 is large at 0.17 and 0.29 respectively, indicating a large effect size. The eta squared value for Variable 5 is 0.10, indicating between a moderate and large effect size.

The analyses of the residuals (Table 2) for Variables 3 (Figures 10 and 11), 4 (Figures 12 and 13), and 5 (Figures 14 and 15) all indicate no statistically-significant difference between the two groups. This means that there was no Group/Time Interaction between the two groups' error bands. It also means that the error bands are statistically equal in size for the two groups on each variable, and that the size of the error bands did not change to a statistically-significant degree for either group over the sessions.

CHAPTER 5
CONCLUSION

Introduction

Air traffic controllers tend to prefer phase-advanced rapidly-rotating work schedules because of the greater breaks they provide between work weeks. Phase-advanced schedules rotate counterclockwise beginning with the evening shift. The controller may work one, two, or three of these evening shifts, depending upon the individualized schedule that he or she works. This type of schedule then allows only an 8-hour break before the controller must return for a day shift, and at the end of the last day shift, the controller encounters another 8-hour quick-turn-around before returning to work the night shift. Individual controllers work a variety of combinations of these three shifts, but the rotation pattern remains the same. By compressing the work schedule during the week in this manner, controllers realize an 80-hour break between work weeks.

Although controllers prefer to work rapidly-rotating schedules, another reason that controllers generally do not work steady, nonrotating schedules is that the FAA discourages this practice.

Traffic is generally light on the night shift and it is felt that controliers permanently on this shift wouid experience a deterioration of proficiency in handling heavier traffic ioads, should they be called upon to do so. Also, social isoiation from professional colleagues would keep these controllers from attending training, briefings, and conferences (Melton, 1985).

The hypotheses addressed by this study were designed to examine whether rapidly-rotating shift work may have an objectiveiy-measurable effect on attention allocation during the day-shift hours (8:00 am to 4:00 pm), when training is most likely to occur in air traffic control facilitles. They were also designed to determine if this type of shift work may cause any learning effects which could be measured via learning curve analysis. This study was deemed necessary because previous studies have demonstrated that air traffic controllers who work rapidly-rotatlng shift schedules report above average ratings of subjectively-rated sleepiness and a lack of alertness during these hours. If objective measures of attention or learning deficiencies could be demonstrated in controllers who work rapidly-rotating shift systems, training treatments could be suggested or devised during training development in order to accommodate these deficiencies, as with

other learner characteristics which need to be addressed for the purpose of maximizing learning.

This study was also deemed necessary because recent research (Redding, 1992) determined that a lack of situation awareness is the primary cause of controller error, and Endsley (1995) developed a model of situation awareness which includes training as a contributing factor to situation awareness in dynamic situations. Each year, a number of controller errors, some of which lead to aircraft accidents, may occur because controllers are affected by circadian dysrhythmia (a misalignment of physiological and/or psychological daily rhythms). If controllers who work certain shift systems possess an attention or learning deficiency, which is a resulting effect of the shift system they work, certain information or procedures may be misinterpreted or overlooked during training sessions. This could later contribute to at least some of the errors which occur in dynamic control situations, while other controller errors may occur due to the effects of circadian dysrhythmia which are manifest during dynamic control situations. If training treatments are devised to accommodate attention or learning deficiencies during training, at least some controller errors may be eliminated in the future.

Discussion

The procedure used in this investigation was necessary because of the probiems involved in recruiting volunteers for such an enduring study at a busy air traffic control facility. The participants could not be randomly assigned to the two groups under investigation because the controllers were already assigned to work schedules through a seniority system. The controllers with the most seniority have more choice in what type of schedule they work, while controllers with less seniority generally get stuck with what is left and are typically assigned to work schedules with little choice in the matter. Because of this, certain personality traits may be a factor in which controllers work which schedules.

Another slight design problem which must be acknowledged is that the testing intervals for the participants were not equal. Some controllers kept fairly regular intervals between testing periods over their 25 sessions, while other controllers kept irregular testing intervals. These slight design problems may somewhat limit the generalization of the results.

The findings of the attention allocation analyses indicate a rejection of the null hypothesis for both hypotheses 1 and 2. Contrary to expectation, Group 1 (Rapidly-Rotating Shift Workers) demonstrated a better attention allocation baseline measure than did

Group 2 (Day/Evening Shift Workers) on both measures: Variable 1 (dial monitoring during the spatial visualization task), and Variable 2 (dial monitoring during the tracking task). The difference between the two groups' means on Variable 1 was 162.07 milliseconds of reaction time, and the difference on Variable 2 was 110.74 milliseconds of reaction time. Although this difference appears to be small, it is important that there is a significant difference between the two groups because attention allocation is of primary concern to the tasks involved in radar control. These tasks include a high degree of concentration on changing traffic situations, and the constant necessity to solve current and potential traffic conflicts. Because of this, dynamic situation awareness research should make note of the differences found in this study and take these results into consideration in future studies. Educational psychology research should consider conducting studies to determine if small differences in attention allocation such as these are significant enough to affect the learning process during instruction.

The analyses of the learning curves for these two variables (Table 2) indicate some interesting findings (Figures 1, 2, 6, 7, 8 & 9). In both measures of attention allocation baseline, Group 1 performed better than did Group 2. In the first measure (attention allocation during spatial visualization), Group 1 improved over time with a

decreasing slope, while Group 2 displayed a fairly flat slope (Figure 1). However, as Table 2 indicates, the eta squared for the difference between the two groups on this measure is only η^2=0.03, indicating less than a moderately-meaningful difference (η^2=0.06). Because of this, further research should be conducted to determine if this effect can be duplicated with a more meaningful outcome. The error bands for both slopes (Figures 6 & 7) stabilized at a statistically significant degree over the sessions, with Group 1 demonstrating an apparently higher degree of stabilization over time than did Group 2.

In the second measure (attention allocation during tracking), neither Group 1 or 2 appears to have improved over the sessions (Figure 2), but Group 1 reached a baseline measure which is better than that of Group 2, as indicated by the t-Test for Variable 2. As with the first measure, both groups stabilized around their mean baseline measures, however, they stabilized at different rates which were found to be statistically significant by the Group/Time Interaction between the the groups' residuals.

As can be seen in figures 6 through 9, the groups' residuals stabilize around their individual group means on both measures of attention allocation. This is strong evidence that the individual differences within each group disappear over the sessions, and that

the differences between the groups' baseline measures really are group differences.

It is also noteworthy that the mean reaction times for both groups are higher during Task 2 than they are during Task 1. Task 2 (tracking), which is a psychomotor activity, appears to require more concentration than does Task 1 (spatial visualization), which is a cognitive task. Both groups demonstrated a lower attention allocation ability while performing the psychomotor task, and neither group improved to a statistically-significant degree on this task over the sessions.

The attention allocation ratings for the groups during the cognitive task (spatial visualization) indicate differential results. As with the psychomotor task, Group 2 again demonstrated no statistically-significant improvement over the sessions. However, Group 1 does improve attention allocation during this task.

The analyses of the learning curves for Variables 3, 4, and 5 demonstrate no statistically-significant learning differences between the two groups. Both groups improved their reaction times for response flexibility at switching resources (Variable 3: changing from Task 2 to Task 1), and at object orientation (Variable 4: spatial visualization). Both groups also improved their tracking error during

the tracking task (Variable 5), and there were no Group/Time Interactions between the groups.

As can be seen in figures 10 through 15, the size of the residuals around each group's mean remains constant over the sessions for these variables. Because of this, there is no stabilization around the groups' means over the sessions, as with the two measures of attention allocation. This is because variables 3, 4, and 5 are learning tasks within the NovaScan testing paradigm, and the individual differences within each group remain constant over the sessions during the learning of these tasks.

Based on these results, it appears that rapidly-rotating shift workers have a better ability at attention allocation than do day and evening shift workers, while completing both cognitive and psychomotor tasks. It also appears that rapidly-rotating shift workers can significantly improve their attention allocation while learning a cognitive task, while day and evening shift workers can not, although the effect size for this result is only slightly meaningful. Finally, it appears that neither rapidly-rotating shift workers nor day and evening shift workers have the ability to improve their attention allocation to a statistically-significant degree while completing a psychomotor task, and these two groups stabilize around their baseline measures for this type of task at differential rates.

These differential results may be due to differences between the two groups in the timing of their sleep-wake cycles, or due to group differences in the amount of total sleep obtained. Either of these factors, or both, may be the cause.

Although the rapidly-rotating shift workers have a rotating sleep-wake cycle, this cycle is kept to a fairly routine change over the course of the week. These workers have two short breaks during shift changes, known as quick-turn-arounds, when they change from the evening shift to the day shift, and when they change from the day shift to the midnight shift. Workers are routinely forced to obtain their sleep during these two short breaks.

Unlike the rapidly-rotating shift workers, day and evening shift workers have only one quick-turn-around each week, which takes place when they change from the evening shift to the day shift. These workers are forced to obtain their sleep at the same time each week during this shift change, but they may be varying their sleep schedule more erratically than the rapidly-rotating shift workers on other nights of the week.

According to Manber et al. (1996), individuals who sleep at irregular schedules (schedules which vary by two hours or more) experience a lack of alertness during the daytime. It may be that the type of sleep-wake cycle practiced by the day and evening shift

workers is irregular and lacks routine. If this is the case, it could also be the case that this type of sleep-wake cycle has a detrimental effect on alertness which is greater than the effect caused by rapidly-rotating shift work, due to the more routine changes in the sleep-wake cycle that the rapidly-rotating shift system provides.

Another possible cause for the comparatively lower daytime attention allocation ability of the day and evening shift workers could be that a lower total amount of sleep is obtained by these workers prior to day shifts. The day and evening shift workers may have a tendency to become "evening types" during their evening shifts and days off. If these workers do not adjust their bedtime to an earlier hour on the evenings preceding their day shifts, they may be experiencing a lack of alertness and lower attention allocation ability during the day shift due to a reduction in total sleep time during these shifts.

The first day shift for the day and evening shift workers already has a reduced sleep period prior to its beginning because of the rapid shift change which occurs at this point each week, during the change from the last evening shift to the day shift (a quick-turn-around). Most schedules would only have one or two more day shifts following this first day shift, and these workers may be maintaining a fairly late bed-time hour prior to these day shifts, as they do for

other nights of the week. All of the other days of the week may be late-evening-oriented for these individuals.

During the data collection phase of this study, a record was kept for the participants' bedtimes, but this record only recorded the participants' bedtimes for the nights prior to their NovaScan sessions. Since these sessions only took place two, three, or possibly four days of the week, this record is inappropriate for determining if irregular sleep-wake cycles were practiced by the participants. However, this record does indicate that the day and evening shift workers' bedtimes on the nights prior to their NovaScan sessions ranged from 9:00 pm to 3:00 am, with an average bedtime of about 11:30 pm, during the course of the investigation. Because of the findings of this study, a more complete and accurate measure of this variable should be taken in future research of this type.

Another point of discussion concerns the possible relationship between controller error and controller shift system type. During the data collection phase of this study, the author gained access to the Jacksonville ARTCC controller error statistics for the 18-month period preceding the investigation. The author conducted a Chi-Square analysis to determine if a higher frequency of controller errors were committed by controllers who worked rapidly-rotating shift

schedules as compared to controllers who worked day and evening shift schedules.

The Chi-Square analysis included the following factors. The total number of controller errors recorded at the Jacksonville ARTCC facility over the 18-month period was 47. Based on the number of controllers working each type of schedule, 28.67 of these errors should have been committed by the day and evening shift workers, and 18.33 errors should have been committed by the rapidly-rotating shift workers, if the chances of committing an error were equal for both groups. The actual number of errors committed by each group was discovered to be 24 errors by the day and evening shift workers, and 23 errors by the rapidly-rotating shift workers. Based on these figures, the result of the Chi-Square analysis was found to be statistically non-significant. Neither group committed a higher number of errors considered to be statistically significant.

Implications

Theoretical

Research in chronopsychology has demonstrated that human psychological and behavioral circadian rhythms are affected by shift work and transmeridian flight. As Adan (1993) indicates, circadian effects are not trivial, and most psychological research has not even

considered time-of-day as a control variable. Due to this, Adan suspects that at least some research results are erroneous.

Although the results of this study are contrary to expectation, the fact that statistically-significant differences were found between the groups lends support to the possibility that the chronopsychological effects of shift work may affect iearning. The rapidly-rotating shift workers not only demonstrated significantly better attention allocation baseline measures than did the day and evening shift workers, they also demonstrated an ability to improve their attention allocation ability during the learning of a cognitive task, while the day and evening shift workers did not. These results add to earlier learning-related research findings in chronopsychology (Englund, 1979; Folkard & Monk, 1980; Monk, 1989), and speak of a need for the consideration of the chronopsychological effects of shift work on learning in Instructional theory, and instructional design.

These results also indicate that certain types of shift work may affect attention on the job. Because shift work schedules may affect individuals' attention allocation ability, research in situation awareness should consider shift schedule as a control variable in future studies.

Practical

Instructional designers and instructors, alike, should be made aware of the diurnal chronopsychological learning effects which have been reported in the literature of chronopsychology. Based on this research (e.g. Englund, 1979; Folkard & Monk, 1980; Monk, 1989; Adan, 1993), these effects have direct implications to the timing of instruction based upon the desired instructional objective.

Practitioners should also be made aware of the negative and positive effects of different shift systems on learning, at different times of the day. With this knowledge, practitioners will become capable of making use of the advantages of the various shift systems, while avoiding their disadvantages, when developing and delivering instruction. As more information concerning the chronopsychological learning effects of shift work becomes available, practitioners may become capable of using the type of shift system worked by an individual to identify the probable learner characteristics associated with that shift system. Practitioners may then develop instructional interventions to address these various learner characteristics.

Performance on the job can be affected by both performance ability, which is influenced by an individual's circadian rhythmic phases at the time of work, and by training, which is affected by instructional design. Instructional design includes the analysis of a

learner's characteristics, which should include an individual's chronopsychological abilities to learn different tasks at different times of the day.

If the results of this study are supported by future research findings, practitioners may classify the comparable lack of attention allocation ability (which does not improve during the learning of a cognitive task) on the part of the day and evening shift workers as a learner characteristic typical of this shift system. An instructional intervention, such as Interactive Computer-Based Training (I-CBT), interactive class discussion, or interactive small-group activities could then be developed to address this learner characteristic so that the trainee could be actively involved in the instructional unit, thereby directing his/her attention to the training task and maximizing the learner's ability to learn, in spite of this deficiency.

Recommendations

Since earlier studies (Melton, 1985; Monk et al., 1988; Saldivar et al., 1977; Smith et al., 1971) indicate that controllers who work rapidly-rotating schedules report a high level of subjective fatigue and a lack of alertness on the day shift, the results of this study seem to indicate that subjective alertness ratings may not necessarily be good indicators of attention allocation ability. In order to determine the relationship between subjective ratings of alertness and objective

measures of attention allocation ability, future research should compare these variables for individuals working various shift systems.

Also, as discussed earlier, future research of this type should keep a continuous record of the participants' sleep-wake cycles. The bedtimes and wake-up times should be logged for each participant during the entire course of an investigation, in order to determine factors such as irregular sleep-wake cycles and total sleep obtained.

Chronopsychology is a fairly new field of study, and, as Adan (1993) points out, there is a great deal of heterogeneity in the results of its research due to the diversity of methods that have been used. One step has been taken to remedy this situation in the classification which Adan has provided to impose coherence on the heterogeneity of the existing research results for both the subjective and objective test used in chronopsychological research. Although this is very beneficial to the field, more work needs to be completed in order to more clearly define psychological and performance rhythms and their responses to various shift systems, so that practitioners in education, and other fields may gain the benefit of the use of predictive planning.

Industry can clearly benefit through a greater understanding of chronopsychology, because workers' performance on the job

determines industrial efficiency, safety, and profit. Since a large percentage of industrial employees work shift work, factors such as efficiency, safety, and profit need to be understood in relation to the chronopsychological effects of shift work, so that interventions may be devised in the work place and in training for the purpose of making improvements.

Because the effects of shift work are experienced by workers in terms of cognitive ability or strategy, and performance at various times of the day, further research should be conducted in order to determine the resulting psychological tendencies, or learner characteristics, associated with different shift systems. It is also recommended that instructional designers and training specialists are made aware of the results of chronopsychological research in both their initial training phases, and in the field. These practitioners should be encouraged to view the chronopsychological tendencies which result from shift work, as learner characteristics which need to be addressed in instruction, in order to help ensure effective learning during training.

One type of chronopsychological research which could be conducted in order to help establish some chronopsychological learner characteristics would be based upon the findings of prior research mentioned earlier. It is known that short-term and long-

term memory, and reading rate and comprehension peak at different times of the day in diurnal situations. Future studies could be designed to determine how these factors are affected by different shift systems. For example, groups of individuals on different shift systems could be given different types of learning tasks (psychomotor, memorization, comprehension, etc.) at different times of the day in order to determine if and how the different shift systems affect the ability of individuals to learn these tasks. This type of research could help to determine the rhythmic fluctuations associated with different learning tasks for individuals on different shift systems. The generalizations derived from this type of research could then become the learner characteristics predicted to be associated with individuals on these different shift systems.

The baseline measures for Variables 3 (response flexibility at switching resources), 4 (reaction time for the spatial visualization task), and 5 (tracking error during the tracking task) were not compared between the two groups in this study, because these variables concern dynamic performance ability. This study was mainly concerned with the learning-curve data on these variables, in order to determine if any learning differences could be found to exist between the groups. As indicated in the results, no learning differences were indicated. However, these type of performance

baseline measures may prove to be of importance in future research which is concerned with dynamic situation awareness. If differences in dynamic performance are demonstrated between groups of individuals working different shift systems, it could be concluded that some shift systems have a chronopsychological effect on dynamic situation awareness. Because of this, it is recommended that these baseline measures are compared between groups who work different shift systems in future research concerning dynamic situation awareness.

Finally, it is recommended that research be conducted with controller error statistics, using large sample sizes, in order to determine if higher frequencies of errors are associated with different shift systems. For example, a Chi-Square frequency analysis could be conducted to determine controller error rates based on controller shift system type for all ATC radar control facilities nation-wide. The data used for this study could include all of the controller errors committed at these facilities for the past three to five years, depending on the availability of records. If a statistically-significant frequency of errors is discovered to be associated with any particular type of shift system, further analysis could then be conducted to determine if the primary factor involved in the errors was degraded job performance during the time of the error, or if

deficiencies during training may have been involved. It may be possible to determine this by reviewing the reasons listed for the errors on the accident reports. Some of the reasons listed, such as "brain lock" could be associated with cognitive conflict caused by the retrieval of inappropriate procedures, or the automation of faulty mental models or scripts for the situation at hand. Psychologist may be able to decipher these terms and associate them with possible cognitive causes. These faulty mental models or scripts could have developed as the result of an attention decrement during training, only to be generated later in dynamic control situations through automatic processing (automation), with little or no conscious awsareness of them.

Presently, situation awareness is considered to be the primary variable involved in controller error, but situation awareness is a broad term and it involves many factors, including training (Endsley, 1995). Further research in situation awareness, including the type described here, will help to isolate and identify the variables which affect situation awareness. Once these variables have been identified, predictive planning measures may be taken to address them early and avoid the negative consequences of not addressing them before they become factors in dynamic situations.

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BIOGRAPHICAL SKETCH

Raymon Michael McAdaragh was born February 19, 1951, in Springfield, Ohio. He spent four years and eight months in the United States Army from 1969 to 1974, serving as an air traffic controller and a flight simulator instrument ground instructor. He completed and received his first Bachelor of Science (B.S.) degree in biology from Christopher Newport University in 1980.

Raymon began his current career as an air traffic control specialist with the Federal Aviation Administration (FAA) in 1981. In 1991, while working with the FAA, he completed his second Bachelor of Science degree in Applied Science and Technology (B.S.A.S.T.) through Thomas A. Edison State College, Trenton, New Jersey. After completing this second Bachelor's degree, he began graduate school at Embry-Riddle Aeronautical University, and completed a Master of Aeronautical Science (M.A.S.) degree in 1994. In August of 1994, he was admitted to the University of Florida where he completed his Ph.D. in educational technology.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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